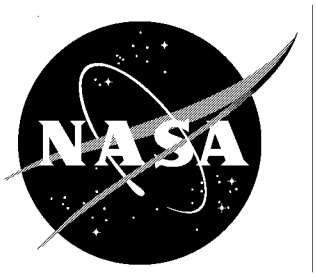
NASA/CP-2001-211029



National Educators' Workshop:Update 2000

Standard Experiments in Engineering, Materials Science, and Technology

Compiled by
Edwin J. Prior and James E. Gardner
Langley Research Center, Hampton, Virginia

James A. Jacobs
Norfolk State University, Norfolk, Virginia

Louis A. Luedtke
National Composite Center, Kettering, Ohio

August 2001

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the lead center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers, but having less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***

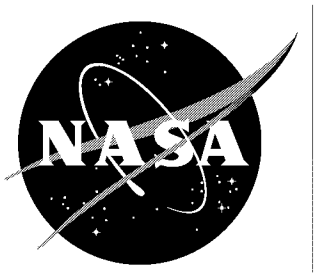
- Email your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Telephone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076-1320

NASA/CP-2001-211029



National Educators' Workshop:Update 2000

Standard Experiments in Engineering, Materials Science, and Technology

Compiled by
Edwin J. Prior and James E. Gardner
Langley Research Center, Hampton, Virginia

James A. Jacobs
Norfolk State University, Norfolk, Virginia

Louis A. Luedtke
National Composite Center, Kettering, Ohio

Proceedings of a workshop sponsored jointly by the National Aeronautics and Space Administration, Washington, DC; Norfolk State University, Norfolk, VA; the National Composite Center, Kettering, Ohio; the National Institute of Standards and Technology, Gaithersburg, MD; the Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN; Wright-Patterson Air Force Base, OH; University of Dayton, Dayton, OH; and Gateway Coalition, Drexel University, Philadelphia, PA and held in
Dayton and Kettering, Ohio
October 29–November 1, 2000

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

August 2001

Available from:

NASA Center for AeroSpace Information (CASI)
7121 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

National Technical Information Service (NTIS)
5285 Port Royal Road
Springfield, VA 22161-2171
(703) 605-6000

PREFACE

NEW:Update 2000, hosted by the National Composite Center, Wright-Patterson Air Force Base, and Wright State University, in Ohio, was held October 29 - November 1, 2000.

The 15th Annual NEW:Update was built on themes, activities and presentations based on extensive evaluations from participants of previous workshops as we continued efforts to strengthening materials education. About 150 participants witnessed demonstrations of experiments, discussed issues of materials science and engineering (MS&E) with people from education, industry, government, and technical societies, heard about new MS&E developments, and chose from nine, three-hour mini workshops in state-of-the-art laboratories. Faculty in attendance represented high schools, community colleges, smaller colleges, and major universities. Undergraduate and graduate students also attended and presented.

This year's hosts provided excellent support. The National Composite Center, Wright-Patterson Air Force Base, the University of Dayton's Research Institute, Wright State University, and Advanced Integrated Manufacturing helped to coordinate the many scientists, engineers, professors and other staff, provided funding, opened their facilities, and developed presentations and activities.

NEW:Update 2000 participants saw the demonstration of about fifty experiments and aided in evaluating them. We also heard technical updates relating to materials science, engineering and technology presented at mini plenary sessions

The experiments in this publication provide valuable guides to faculty who are interested in useful activities for their students. The material was the result of years of research aimed at better methods of teaching materials science, engineering and technology. The experiments developed by faculty, scientists, and engineers throughout the United States and abroad add to the collection from past workshops. There is a blend of experiments on new materials and traditional materials in addition to engineering concepts.

Experiments underwent an extensive peer review process. After submission of abstracts, selected authors were notified of their acceptance and given the format for submission of experiments. Experiments were reviewed by a panel of specialists through the cooperation of the International Council for Materials Education (ICME). Comments from workshop participants provided additional feedback, which authors used to make final revisions, which were then submitted to the NASA editorial group for this publication.

The ICME encourages authors of experiments to make submissions for use in the Journal of Materials Education (JME). The JME offers valuable teaching and curriculum aids, including instructional modules on emerging materials technology, experiments, book reviews, and editorials to materials educators.

As with previous NEW:Updates, critiques were made of the workshop to provide continuing improvement of this activity. The evaluations and recommendations made by participants provide valuable feedback for the planning of subsequent NEW:Updates.

NEW:Update 2000 and the series of workshops that go back to 1986 are, to our knowledge, the only national workshops or gatherings for materials educators that have a focus on the full range of issues on strategies for better teaching about the full complement of materials. NEW:Updates, with its diversity of faculty, industry, and government MSE participants, served as a forum for both formal and informal issues facing MSE education that ranged from the challenges of keeping faculty and students abreast of new technology to ideas to ensure that materials scientists, engineers, and technicians maintain the proper respect for the environment in the pursuit of their objectives.

We demonstrated the second edition of *Experiments in Materials Science, Engineering & Technology, (EMSET2) CD-ROM* with over 450 experiments from NEW:Updates. This CD-ROM is another example of cooperative efforts to support materials education. The primary contributions came from the many authors of the demonstrations and experiments for NEW:Updates. Funding for the CD came from both private industry and federal agencies. Please see the attached information for obtaining the CD. To obtain a demonstration edition or to order the full version of *EMSET2 CD-ROM* call 1-800-922-0579 or go to Internet site http://MST-Online.nsu.edu and link to the World of Materials, Science, & Technology.

We express our appreciation to all those who helped to keep this series of workshops viable. Special thanks go to those on our national organizing committee, management team, hosts, sponsors, and especially those of you who developed and shared your ideas for experiments, demonstrations, and novel approaches to teaching.

We hope that the experiments presented in this publication will assist you in teaching about materials science, engineering and technology. We would like to have your comments on their value and means of improving them. Please send comments to Jim Jacobs, School of Science and Technology, Norfolk State University, Norfolk, Virginia 23504.

MANAGEMENT TEAM

James A. Jacobs
Workshop Co-chairperson
Norfolk State University

Louis A. Luedtke
Workshop Co-chairperson
National Composites Center

Diana P. LaClaire
Assistant Director
Norfolk State University

Robert Berrettini
International Council on Materials Education

Paul Brown
International Council on Materials Education

Raymond G. Boeman
Oak Ridge National Laboratory

S. Raj Chaudhury
Norfolk State University

Harry J. Couch
National Composite Center

Jeanne Deatherage
ASM International Foundation

Leonard W. Fine
Columbia University

James E. Gardner
NASA Langley Research Center

Said Jahanmir
National Institute of Standards and Technology

Kenneth L. Jewett
Materials Science & Engineering Laboratory-NIST

Thomas F. Kilduff
Thomas Nelson Community College

Steve Krause
Arizona State University

P. K. Mallick
University of Michigan-Dearborn

James V. Masi
Northeast Center for Telecommunication Technologies

Alfred E. McKenney
IBM Corporation, Retired

Robert L. Mott
University of Dayton

Tony Polsinelli
Advanced Integrated Manufacturing Center

Edwin Prior
National Aeronautics and Space Administration

Heidi Ries
Air Force Institute of Technology

Laura L. Sullivan
American Society for Engineering Education

Katie E. G. Thorp
AFRL/MLBC Wright-Patterson Air Force Base

C. David Warren
Oak Ridge National Laboratory

Acknowledgements

We greatly appreciate the support provided by these organizations:

Department of Energy Office of Energy Efficiency and Renewable Energy
National Composite Center
National Aeronautics & Space Administration Langley Research Center
School of Science and Technology Norfolk State University
Materials Science & Engineering Laboratories-NIST
Energy Efficiency and Renewable Energy Program Oak Ridge National Lab
Air Force Research Laboratory Materials and Manufacturing Directorate Wright-Patterson AFB
United States Automotive Materials Partnership
Center for Lightweight Materials & Processing University of Michigan-Dearborn
The ASM International Foundation
University of Dayton
Gateway Engineering Coalition
Advanced Integrated Manufacturing Center
American Society for Engineering Education
Columbia University
Dayton Power & Light
Edison Welding Center
Fifth Third Bancorp
Gottschlick & Portune
Hardcore Composites Operations LLC
International Council for Materials Education
McDonald Investments (Key Bank)
Mead World Headquarters
Northeast Center for Telecommunication Technologies
Reynolds & Reynolds
Wright State University

CONTENTS

WORKSHOP PRESENTATIONS

REVIEWERS FOR NEW:UPDATE 2000

Else Breval
Senior Research Associate
Materials Research Laboratory
The Pennsylvania State University

Witold Brostow
Professor of Materials Science
Center for Materials Characterization
University of North Texas

L. Roy Bunnell
Southridge High School

William Callister
Adjunct Professor of Metallurgy
University of Utah

James Clum
Director, Center for Industrial & Manufacturing Engineering
University of Detroit, Mercy

Wayne L. Elban
Professor of Engineering
Loyola College, Maryland

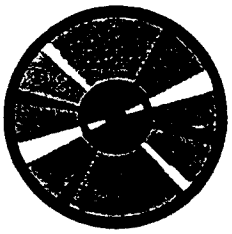
Mark Palmer
Assistant Professor of Mechanical Engineering
Virginia Commonwealth University

Ransom Douglas
Assistant Professor Industrial Technology
Norfolk State University

Technical notebooks were provided by
NASA LANGLEY RESEARCH CENTER

Announcements of the workshop were provided by
The ASM International Foundation

The New EMSET2 CD ROM from Jim Jacobs, Al McKenney and Prentice Hall Publishing



The CD ROM *Experiments in Materials Science, Engineering and Technology 2* (*EMSET2*) will be available soon!

For more than a decade, the National Educators' Workshops have enabled educators to participate in seminars of peer-reviewed experiments and demonstrations in materials science, engineering and technology. Following each workshop, these papers were published in an annual compendium, with the generous support of NASA.

Now, with the assistance from NASA and many other governmental, educational and industrial organizations, we have been able to publish thirteen yearly volumes of these papers in an easily used format, the *EMSET2* CD ROM. This is an expanded and updated version of the original *EMSET* CD ROM. This new version runs on all platforms and uses the universally-accepted Adobe Acrobat format for retrieval, display and printing.

To help the user, the nearly 350 experiments and demonstrations are indexed under the following seven categories: 1)Structure, Testing and Evaluation, 2)Metals, 3)Polymers, 4)Ceramics, 5)Composites, 6)Electronic and Optical Materials, and 7)Materials Curriculum. The user can find the material he or she wants by browsing the tables of contents or by searching for author, title, institution, or key word. Then the documents can be reviewed and used by displaying an exact image of the paper(s), including text, graphs, pictures, formulae, etc. or by printing the paper as written or even by copying the text and/or graphics into a word processor for editing.

To preview an individual demo version (available Summer 2000) please reference ISBN 0130194751 and contact:
Melissa Orsborn
Marketing Assistant
445 Hutchinson Ave. Fourth Floor
Columbus, Ohio 43235
1-614-841-3622
Melissa_Orsborn@prenhall.com
Or
To purchase the complete *EMSET2* CD ROM (available Summer 2000) please reference ISBN 0130305340 and contact:
Prentice Hall Customer Service
1-800-922-0579

PARTICIPANTS

Row 1 front (L to R):
A. Eslami, W. Elban, D. Yarnell, I. H. Jain, H. Jain, D. Evans, J. Jacobs, J. Marshall, F. Ekpo, H. Ries, D. LaClaire
Row 2 (L to R):
C. Wall, A. Witt, B. Ross, L. Fine, H. Abramowitz
Row 3 (L to R):
T. Roberts, R. Chung, R. Singh, E. Widener, M. Shuman, L. Aldridge, M. Czayka, N. Fabris, B. McCoy, A. McKenney, S. Helba
Row 4 (L to R):
S. Krause, R. Schroeder, G. Holmes, B. Ullrich, R. Berrettini, J. Gardner, R. Mott, S. McLennan, A. Karplus, R. Bunnell, A. Rengan
Row 5 back (L to R):
M. Murton, R. Griffin, S. Kennedy, L. Luedtke, M. Rudes, T. Kilduff, P. Joyce, M. Meier

NATIONAL EDUCATORS' WORKSHOP 2000
PARTICIPANTS

Harvey Abramowitz
Department of Engineering
Purdue University - Calumet
2200 169th Street
Hammond, IN 46323
219-989-2473
harveya@calumet.purdue.edu

Wade Adams
Chief Scientist
AFRL/MLBC
2977 P Street, Suite 1
Materials and Manufacturing Directorate
Air Force Research Laboratory
Wright-Patterson Air Force Base
Ohio 45433
937-255-6825
wade.adams@afrl.af.mil

Lori Aldridge
Northwestern High School
2503 W. Main Street
Rockhill, SC 29732
803-547-0969
ll1516@aol.com

Ronald B. Bucinell
Union College
Department of Mechanical Engineering
Schenectady, NY 12308
518-388-6023 (Pat 6264)
bucinelr@union.edu

Robert Berrettini
209 Kenmar Drive
Monroeville, PA 15146-1717
412-373-7975
berrettini@juno.com

L. Roy Bunnell
6119 W. Willamette
Kennewick, WA 99336
509-734-3800
Bunnro@ksd.org

W. Richard Chung
Department of Chemical and Materials Engineering
San Jose State University
San Jose, CA 95192-0082
408-924-3927
wrchung@email.sjsu.edu

Michelle Churma
Prentice-Hall, Inc.
445 Hutchinson Avenue 4th floor
Columbus, OH 43235
614-841-3636
Michelle_Churma@prenhall.com

Michael A. Czayka
Kent State University
3325 West 13th Street
Ashtabula, OH 44404
440-964-4266
czayka@astabula.kent.edu

Jai N. Dahiya
Physics Department
Southeast Missouri State University
One University Plaza
MS 6600
Cape Girardeau, MO 63701
573-651-2390
dahiya@physics.semo.edu

Tom Dearlove
GM R&D Center
MC: 480-106-316
30500 Mound Road
Warren, MI 48090-9055
810-986-1267
thomas.j.dearlove@gm.com

Jeane Deatherage
Administrator,Foundation Programs
ASM International Foundation
Materials Park, OH 44073-0002
1-800-336-5152
jdeather@asminternational.org

Efremfon Frank Ekpo
Bethune-Cookman College
640 Dr. M. M. Bethune Blvd.
Daytona Beach, FL 32114
904-255-1401 ext. 532
ekpoe@cookman.edu

Wayne L. Elban
Loyola College
4501 N. Charles Street
Baltimore, MD 21210
410-617-2853
welban@loyola.edu

John Elwood
Claflin College
400 Magnolia Street
Orangeburg, SC 29115
803-535-5242

Akbar Eslami
Elizabeth City State University
Technology Department
Elizabeth City, NC 27909
252-335-3441
aeslami@mail.ecsu.edu

Don L. Evans
Director, Center for Research on Education
in Science, Math, Engineering, & Technology
Arizona State University
Tempe, AZ 85287-5006
480-965-5350
devans@asu.edu

Daniel Eylon
Professor and Director
Graduate Materials Engineering
University of Dayton
300 College Park
Dayton, OH 45469-0240
937-229-2551
eylon@notes.udayton.edu

Neda S. Fabris
Mechanical Engineering
California State University, Los Angeles
5151 State University
Los Angeles, CA 90032
213-343-5218
nfabris@exchange.calstatela.edu

Leonard W. Fine
Department of Chemistry
Columbia University in the
City of New York
Havemeyer Hall
New York, NY 10027
212-854-2017
fine@chem.columbia.edu

Michael Freed
Advanced Integrated Manufacturing Centr

Morton Friedman
Columbia University
500 West 120th Street
Room 510 Mudd
New York, NY 10027
212-854-2986
friedman@columbia.edu

James E. Gardner
Technical Staff Assistant
NASA Langley Research Center
Building 1219, Room 217
MS 118
Hampton, VA 23681-0001
757-864-6003
j.e.gardner@larc.nasa.gov

Dennis Gerdeman
University of Dayton

Mark Glasper
Director of Communications
The American Ceramic Society
P. O. Box 6136
Westerville, OH 43086-6136
614-794-5898
mglasper@acers.org

Richard B. Griffin
Department of Mechanical Engineering
Texas A&M
College Station, TX 77843
409-845-9779
rgriffin@mengr.tamu.edu

William Grissom
Central State University
Manufacturing Engineering Dept.
1400 Brush Row Road
Wilberforce, OH 45384

Ed Hagerman
GM R&D Center
30500 Mound Road
Warren, MI 48090-9055

Steve Helba
Prentice Hall
445 Hutchinson Avenue
Columbus, OH 43235
800-228-7854
Steve_Helba@prenhall.com

Gale A. Holmes
Polymers Division (854)
Polymers Building (224), Room B116
National Institute of Standards and Technology
100 Bureau Drive, Stop 8543
Gaithersburg, MD 20899-8543
301-975-5280
gale.holmes@nist.gov

James A. Jacobs
Norfolk State University
700 Park Avenue
Norfolk, VA 23504
757-823-8109
jajacobs@.nsu.edu

H. Jain
Department of Materials Science and Engineering
Lehigh University
5 East Packer Avenue
Bethlehem, PA 18015-3195
610-758-4217
hj00@Lehigh.edu

Isha H. Jain
Student

Peter Joyce
U. S. Naval Academy
590 Holloway Road
Annapolis, MD 21402
410-293-6533
pjoyce@usna.edu

Alan K. Karplus
Department of Mechanical Engineering
Western New England College
Springfield, MA 01119-2684
413-782-1220
akarplus@wnec.edu

Stephen K. Kennedy
RJ Lee Group, Inc.
350 Hochberg Road
Monroeville, PA 15146
724-325-1776
skennedy@rjlg.com

Thomas F. Kilduff
504 Brafferton Circle
Hampton, VA 23663
757-857-0272
tkilduff@whro.net

Don Klosterman
Laboratory for Research on Electron
Beam Curing of Composites
University of Dayton
300 College Park
Dayton, OH 45469-0131
937-229-2517
Don.Klosterman@notes.udayton.edu

Steve Krause
Dept. of Chemical and Materials Engineering
Arizona State University
Tempe, AZ 85287-2050
skrause@asu.edu

Diana P. LaClaire
Norfolk State University
2401 Corprew Avenue
Norfolk, VA 23504
757-823-9072
dplaclaire@nsu.edu

Louis A. Luedtke
National Composites Center
2000 Composites Drive
Kettering, OH 45420
937-297-9512
lluedtke@compositecenter.org

P. K. Mallick
Department of Mechanical Engineering
University of Michigan-Dearborn
Dearborn, MI 48128
313-593-5119
pkm@umich.edu

John Marshall
University of Southern Maine
John Mitchell Center
Gorham, ME 04038
207-780-5447
jmarshal@usm.maine.edu

James V. Masi, Director
Northeast Center for Telecommunications
Technologies
One Federal Street
Springfield, MA 01105
413-731-3155
masij@email.msn.com

Seaton McLennan
Linn Benton Community College
6500 SW Pacific Blvd.
Albany, OR 97321
541-917-4630
mclenns@ml.lbcc.cc.or.us

Robert A. McCoy
Mechanical Engineering Department
Youngstown State University
Youngstown, OH 44555
330-742-1736
ramccoy@cc.ysu.edu

Alfred E. McKenney
516 Fairfax Way
Williamsburg, VA 23185
757-221-0476
aem2@prodigy.net

Mike Meier
University of California Davis
Department Chemical Engineering & Materials Science
Davis, CA 95616
530-752-5166
mlmeier@ucdavis.edu

Mike Melton
National Composite Center

Vijay Modi
Columbia University in the City of New York
240 SW Mudd
New York, NY 10027
modi@columbia.edu

Pablo E. Montemartini
University of North Texas
Materials Science Department
Denton, TX 76203-5310
pmontema@yahoo.com

Robert L. Mott
University of Dayton
Engineering Technology
300 College Park
Dayton, OH 45469-0249
937-229-2685
Robert.Mott@notes.udayton.edu

Mark Murton
National Composite Center
2000 Composite Drive
Kettering, OH 45420
937-297-9528
Mmurton@CompositeCenter.org

B. Ramakrishna
Center for Solid State Sciences
Arizona State University
Tempe, AZ 85287-1704
480-965-6560
bramakrishna@asu.edu

Alessandro Rengan
Central State University
Manufacturing Engineering Dept.
1400 Brush Row Road
Wilberforce, OH 45384
937-376-6429
arengan@csu.ces.edu

Heidi R. Ries
Air Force Institute of Technology/ENR
2950 P Street, Bldg. 640
Wright-Patterson Air Force Base, OH 45433-7765
937-255-3636 ext. 4544
Heidi.Ries@afit.af.mil

Thomas E. Roberts
Milwaukee Area Technical College
700 W. State Street
Milwaukee, WI 53233
414-297-7280
robertte@matc.edu

Bill Ross
Muskegon Community College
221 S. Quarterline Road
Muskegon, MI 49442
616-777-0367
rossb@muskegon.cc.mi.us

Scott Reeve
National Composite Center

Merrill Rudes
Energy Concepts, Inc.
595 Bond Street
Lincolnshire, IL 60069
847-821-1900 ext. 312
ecisales1@aol.com

Tony E. Saliba
Professor and Chairman
Chemical and Materials Engineering Dept.
University of Dayton
Dayton, OH 45469-0246
937-229-2627
Tony.Saliba@notes.udayton.edu

Correen Schneider
National Composite Centr
2000 Composite Drive
Kettering, OH 45420
937-297-9521
cschneider@compositecenter.org

Raoul Schroeder
Bowling Green State University
Physics & Astronomy Dept.
104 Overman Hall - Ridge Street
Bowling Green, OH 43403
419-372-8785
raoul@kottan-labs.bgsu.edu

Kurt C. Schulz
Khoury Hall
University of the Pacific
Mechanical Engineering Department
3601 Pacific Avenue
Stockton, CA 95211
209-946-3081
kschulz@uop.edu

Kathy Schweinfurth
Wright-Patterson Air Force Base
Educational Outreach Office Coordinator
Area B., Bldg. 45, Room 01
Wright Patterson Air Force Base, OH 45433
937-255-0692
Kathleen.Schweinfurth@wpafb.af.mil

Mike Shuman
Kent State University
Electron Beam Technology Program
NEO Beam
P. O. Box 1028
Middlefield, OH 44062
440-632-1780
mshuman@kent.edu

Ram N. Singh
St. Louis Community College at Flo. Valley
3400 Pershall Road
St. Louis, MO 63135-1499
314-595-2311
rsingh@stlcc.cc.mo

Karla Strong
AFRL/MLBC
2941 P Street
Wright-Patterson Air Force Base
OH 45433-7750

Donna C. S. Summers
University of Dayton
Industrial Engineering Technology
300 College Park Drive
Dayton, OH 45469-0249
937-229-2974
dsummers@engr.udayton.edu

Katie E. G. Thorpe
AFRL/MLBC
Wright-Patterson Air Force Base
OH 45433
katie.thorp@afrl.af.mil

Tia Benson Tolle
AFRL/MLBC
2941 P Street, Room 136
Wright-Patterson Air Force Base
Oh 45433-7750
Tia.BensonTolle@wpafb.af.mil

Bruno Ullrich, Assistant Professor
Dept. of Physics & Astronomy
Center for Materials Science
Bowling Green State University
Bowling Green, OH 43403-0224
419-372-7245
bruno@newton.bgsu.edu

Carlos E. Umana
Department of Materials
School of Mecanical Engineering
University of Costa Rica
San Pedro, Costa Rica
506-207-4548
caruma@terraba.fing.ucr.ac.cr

Curtiss E. Wall
Norfolk State University
700 Park Avenue
Norfolk, VA 23504
757-823-9571
cewall@nsu.edu

James W. Watson
Senior Research Engineer
A. K. Steel Corp.
Middletown, OH
513-727-5832
Jay_Watson@aksteel.com

James M. Whitney
Dept. of Civil and Environmental Engineering
and Engineering Mechanics
University of Dayton
300 College Park
Dayton, OH 45469-0243
937-229-3847
James.Whitney@notes.udayton.edu

Edward L. Widener
Purdue University
Knoy Hall 119
West Lafayette, IN 47907-1317
765-494-7521
elwidener@tech.purdue.edu

August Witt
Massachusetts Institute of Technology
77 Massachusetts Avenue, Room 13-4138
Cambridge, MA 02139
617-253-5303
afwitt@mit.edu

Debbie Yarnell
Prentice Hall/Pearson Education
5H084
One Lake Street
Upper Saddle River, NJ 07458
201-236-7805
debbie_yarnell@prenhall.com

PROFESSOR

Robert Mott - University of Dayton

STUDENTS' NAMES

James Coleman
Jason Glock
Carolyn Gudaitis
Tim Hague
Ben Lambers
Brian Noel
John Rowland
Lynn Stonebrook
Zach Williams

PROFESSOR

Robert Chasnov - Cedarville University

STUDENTS' NAMES

Torrey Wycliffe Adams
Charles P. Aman
Lindy A. Anderlini
John Thomas Bailey
Andrew L. Bennett
Ehren Duane Brinkmeier
Jonathan Samuel Brockman
Joseph S. Burke
Bradford Wesley Desatnik
David James Drye
Lance Everett Ferguson
Nicholas A. Forshee
Nicholas Edward Grisco
William Hamilton Jenks
Jared M. Koverman
Jeremy Alan Maller
Kenneth L. Mansfield
Timothy John McCorkle
Kenneth Jay Moore, Jr.
Stephen C. Moseley
Matthew Paul Nealis
Bradley Eugene Nicol
Steven Mikel Page
Stephen Wesley Parker, Jr.
Christopher Recktanwald
Francis Wingate Saul III
Andrew Douglas Schmidt
Cameron James Stephan
William John Walker
Brian Maris White
David P. Wolf
Adam J. Yingling

NATIONAL EDUCATORS' WORKSHOP

Update 2000: Standard Experiments in Engineering Materials, Science, and Technology

October 29 - November 1, 2000 - Kettering, Ohio

Sponsored by

Department of Energy
Office of Energy Efficiency and
Renewable Energy

National Composite Center

National Aeronautics & Space
Administration
Langley Research Center

School of Science and Technology
Norfolk State University

Materials Science &
Engineering Laboratories-
NIST

Energy Efficiency and Renewable
Energy Program
Oak Ridge National Laboratory

Air Force Research Laboratory
Materials and Manufacturing Directorate
Wright-Patterson Air Force Base

United States Automotive
Materials Partnership

Center for Lightweight Materials
and Processing
University of Michigan - Dearborn

The ASM International Foundation

University of Dayton

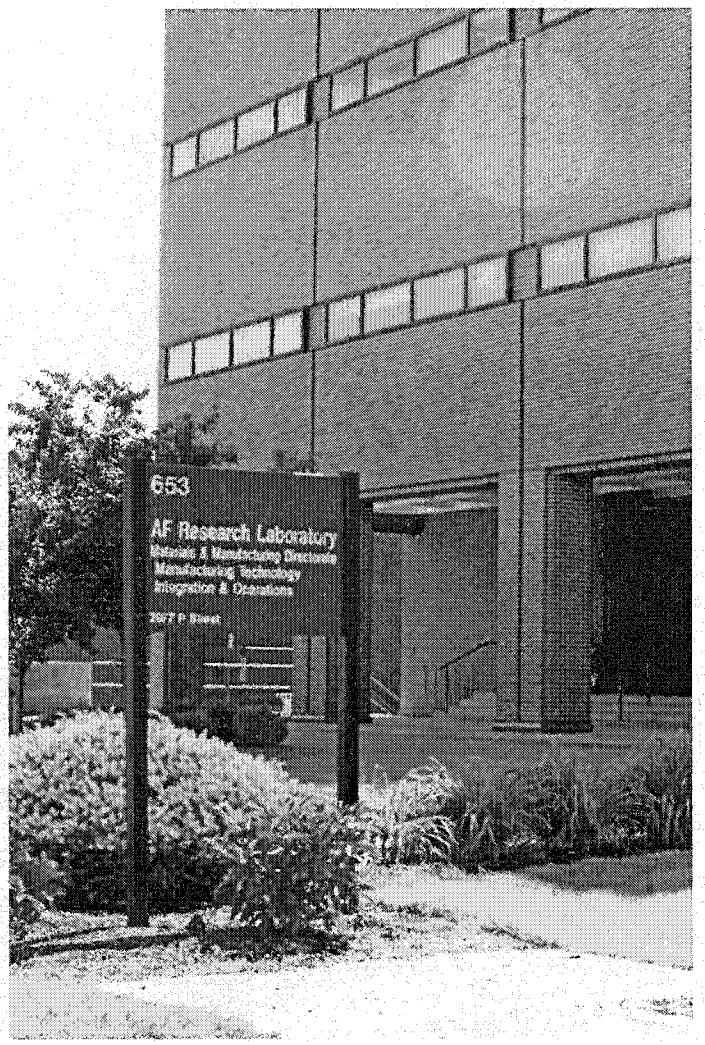
Gateway Engineering Coalition

with the support of

Advanced Integrated Manufacturing Center
Columbia University
Edison Welding Center
Gottschlick & Portune
International Council for Materials Education
Mead World Headquarters
Reynolds & Reynolds

American Society for Engineering Education
Dayton Power & Light
Fifth Third Bancorp
Hardcore Composites Operations LLC
McDonald Investments (Key Bank)
Northeast Center for Telecommunication Technologies
Wright State University


NATIONAL COMPOSITE CENTER

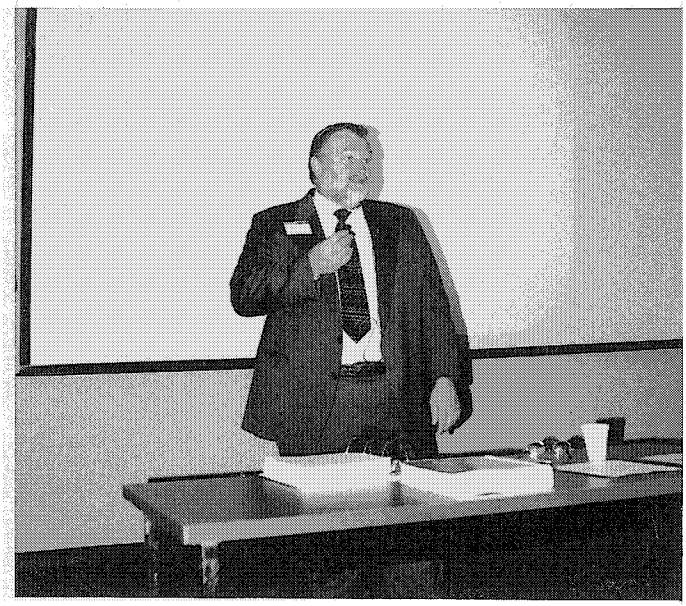

653
AF Research Laboratory
Manufacturing Technology
Integration & Operations

WELCOME

OPENING SESSION

Jim Jacobs

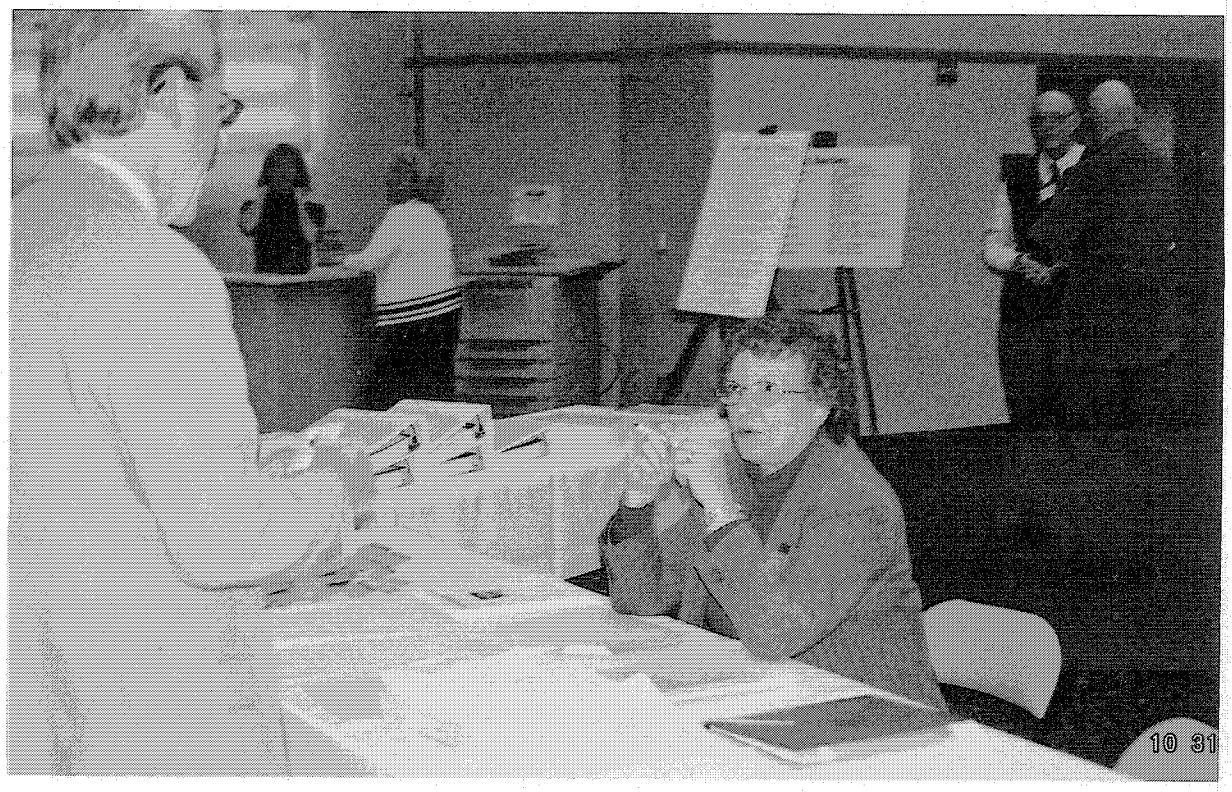
OPENING SESSION



Louis A. Luedtke
National Composite Center

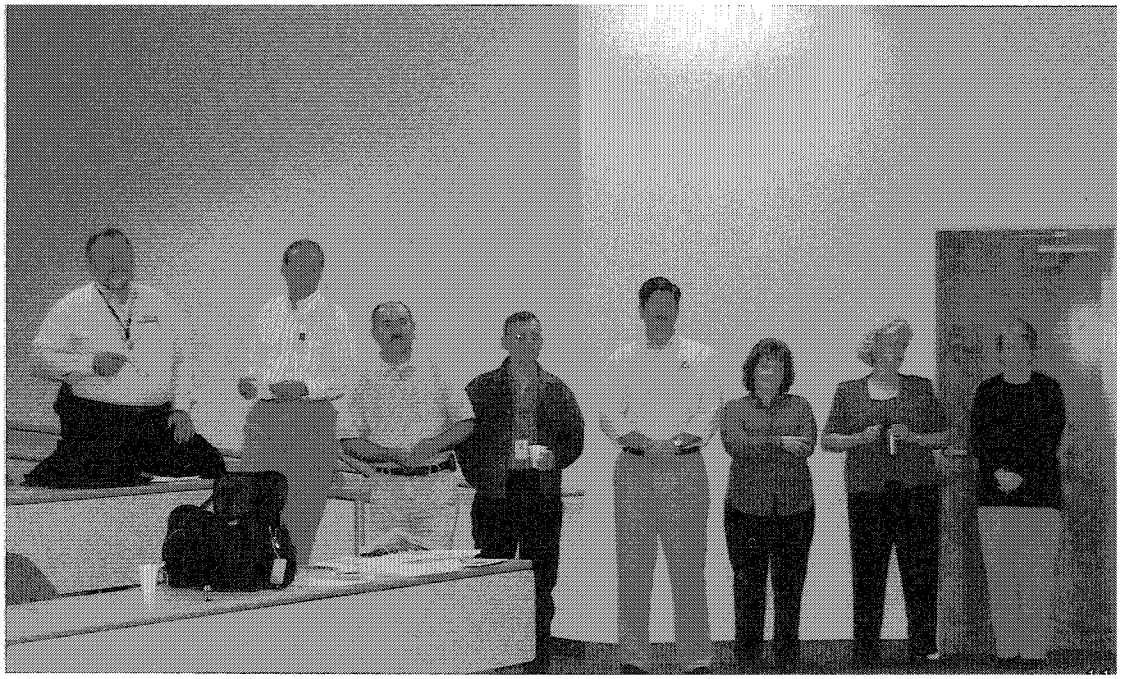
Heidi R. Ries
Wright Patterson Air Force Base

REGISTRATION

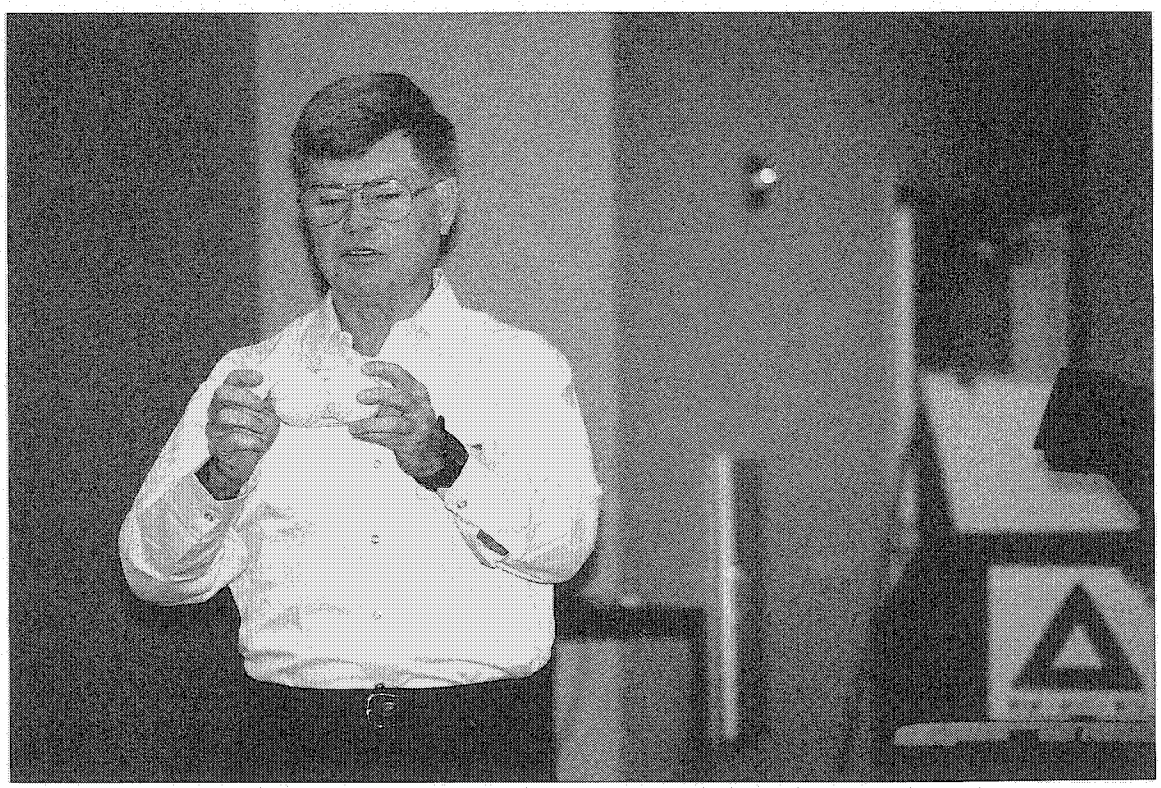


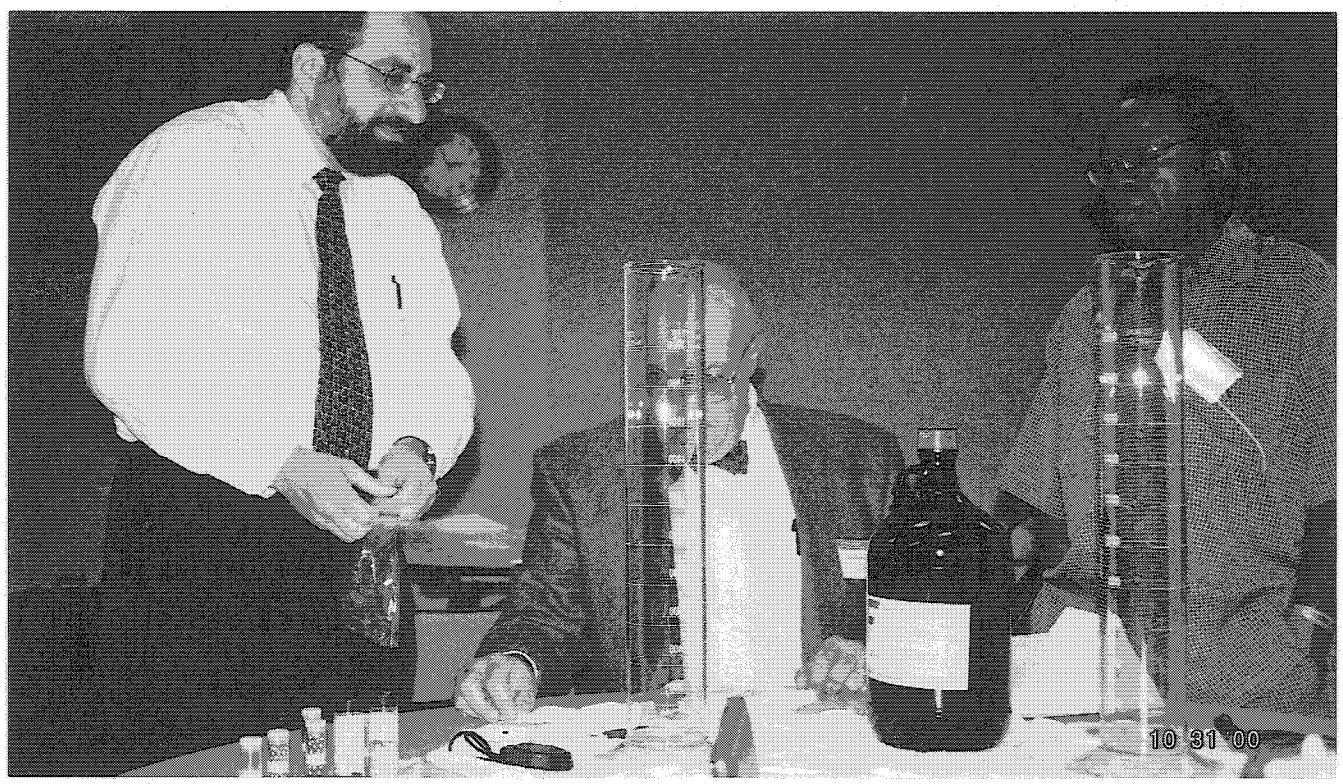
Diana LaClaire

NATIONAL COMPOSITE CENTER STAFF

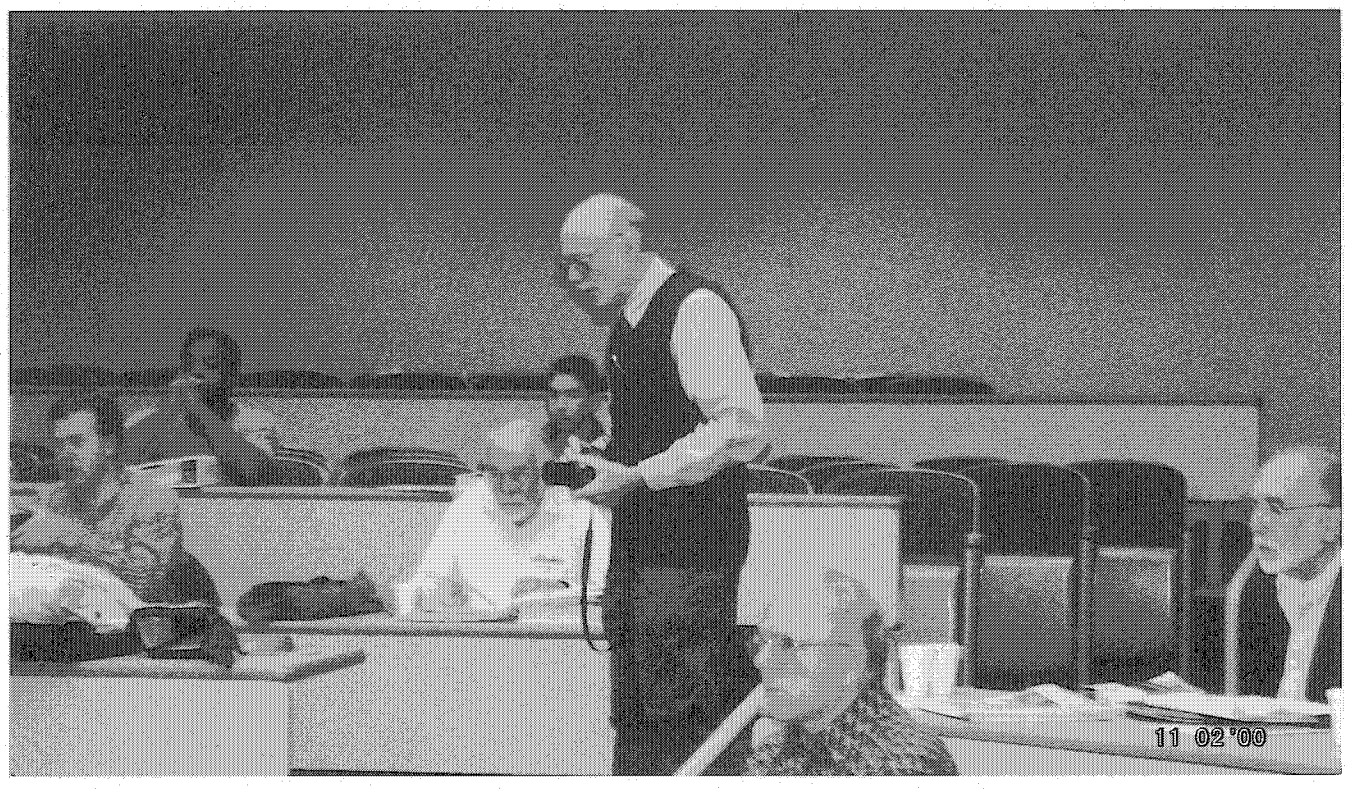


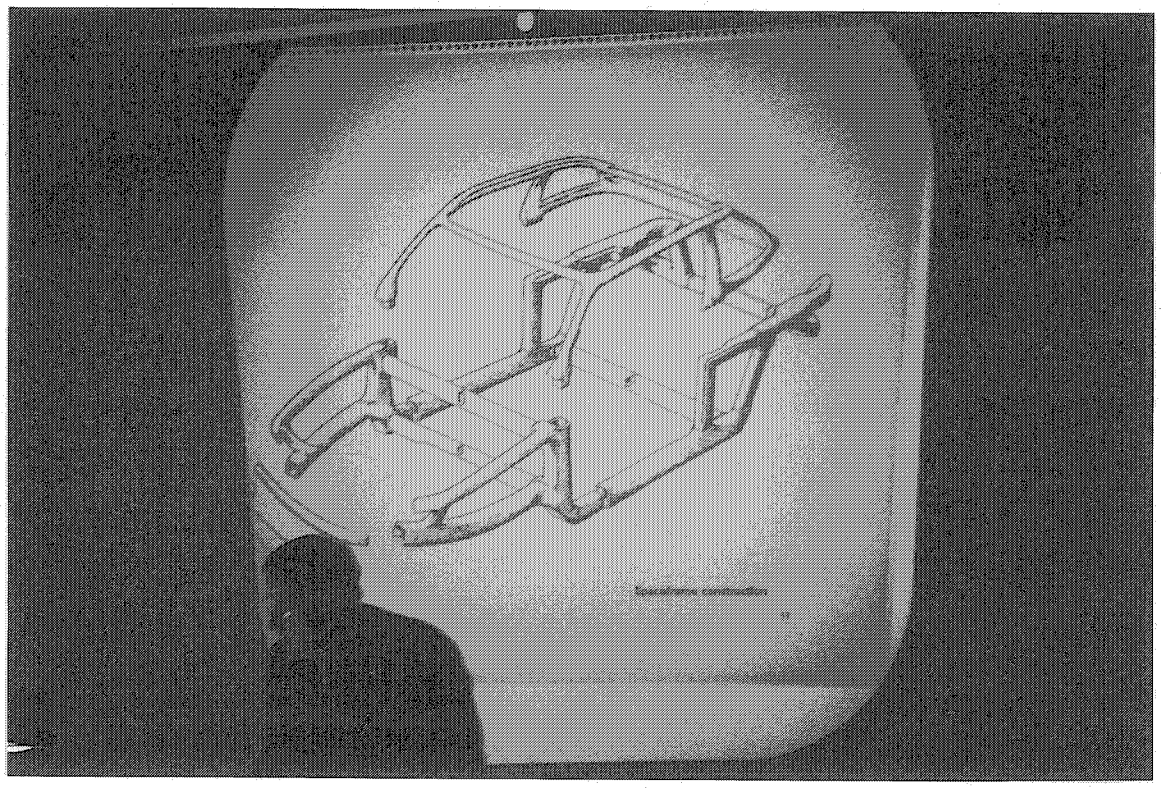
SESSIONS



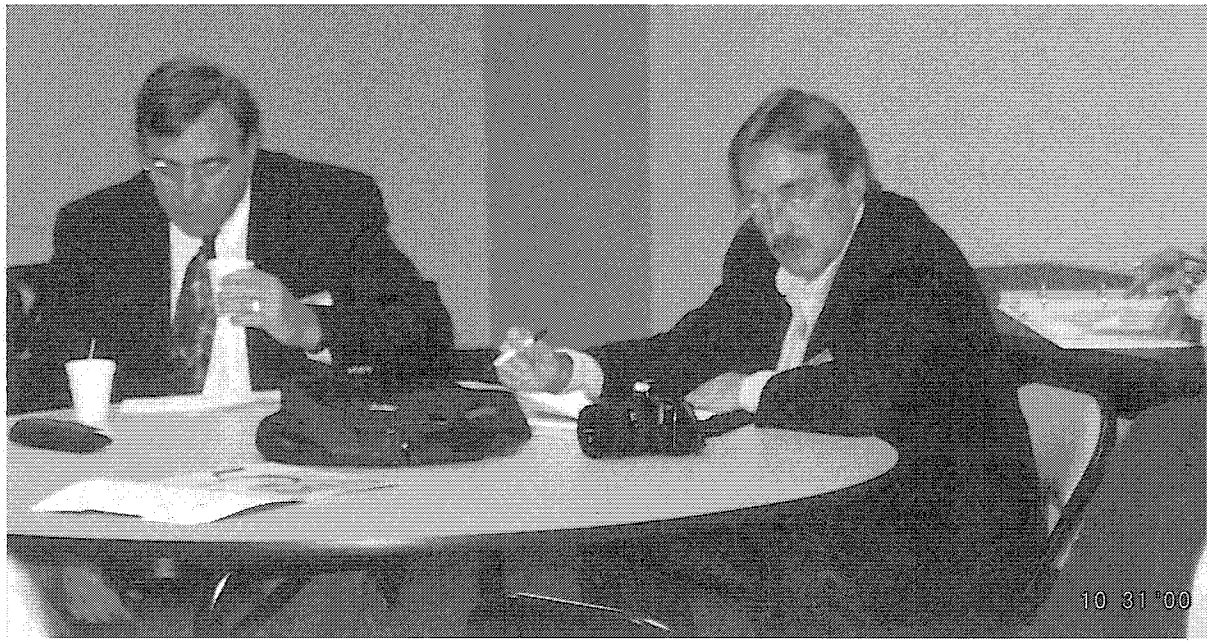

10 31 00

SESSIONS
(concluded)

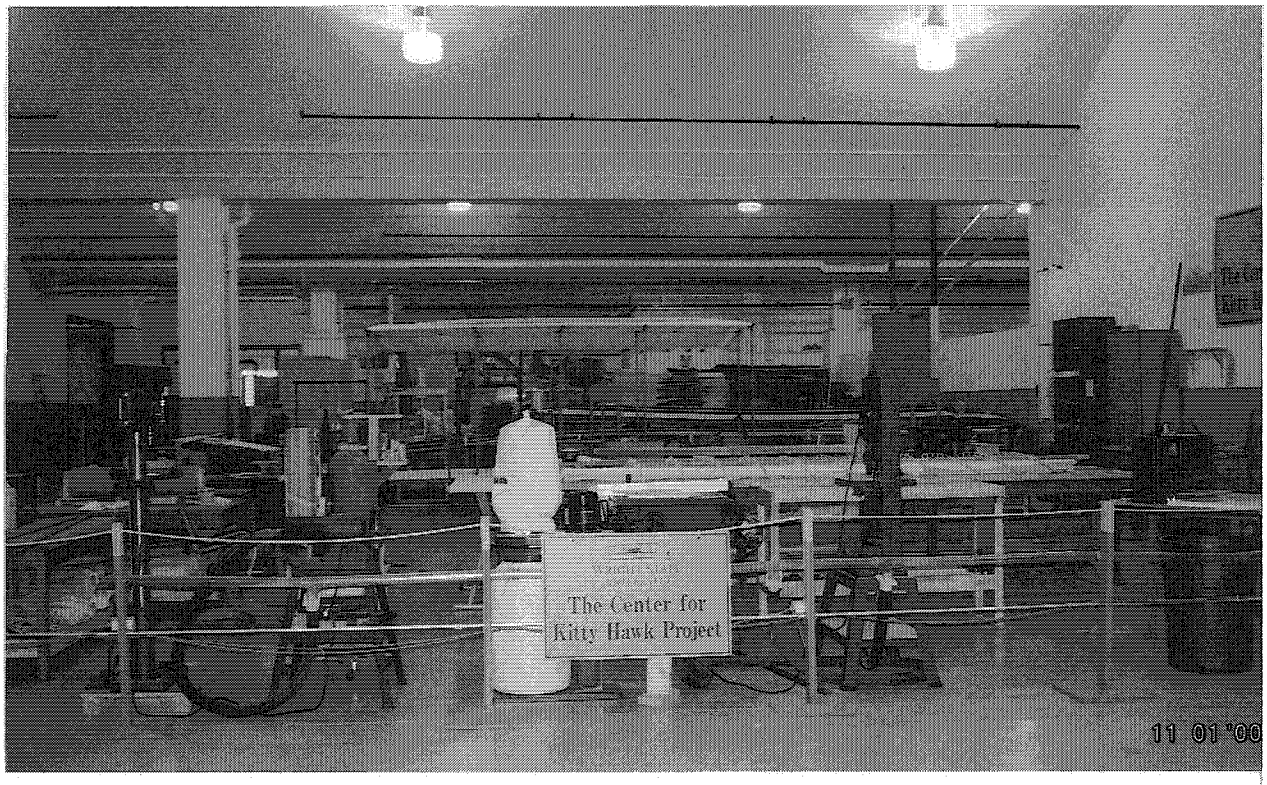


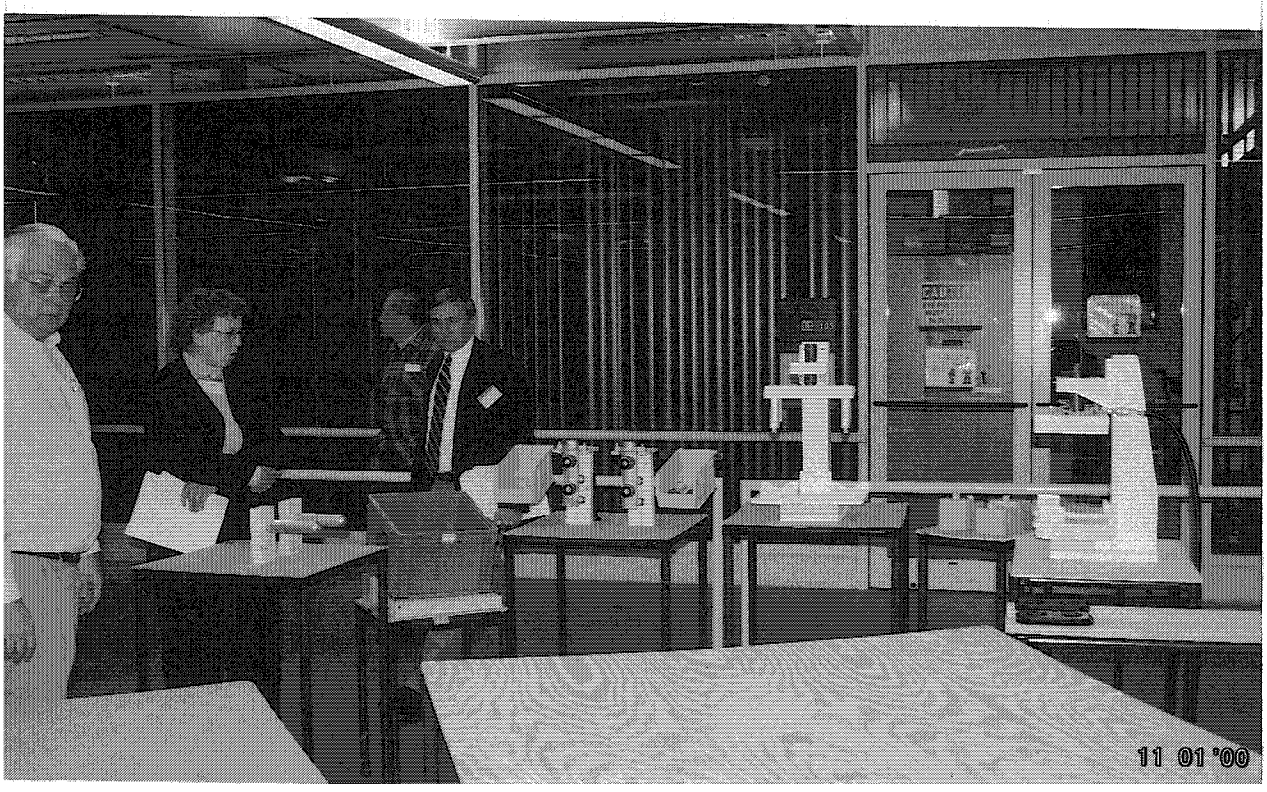


BREAKS

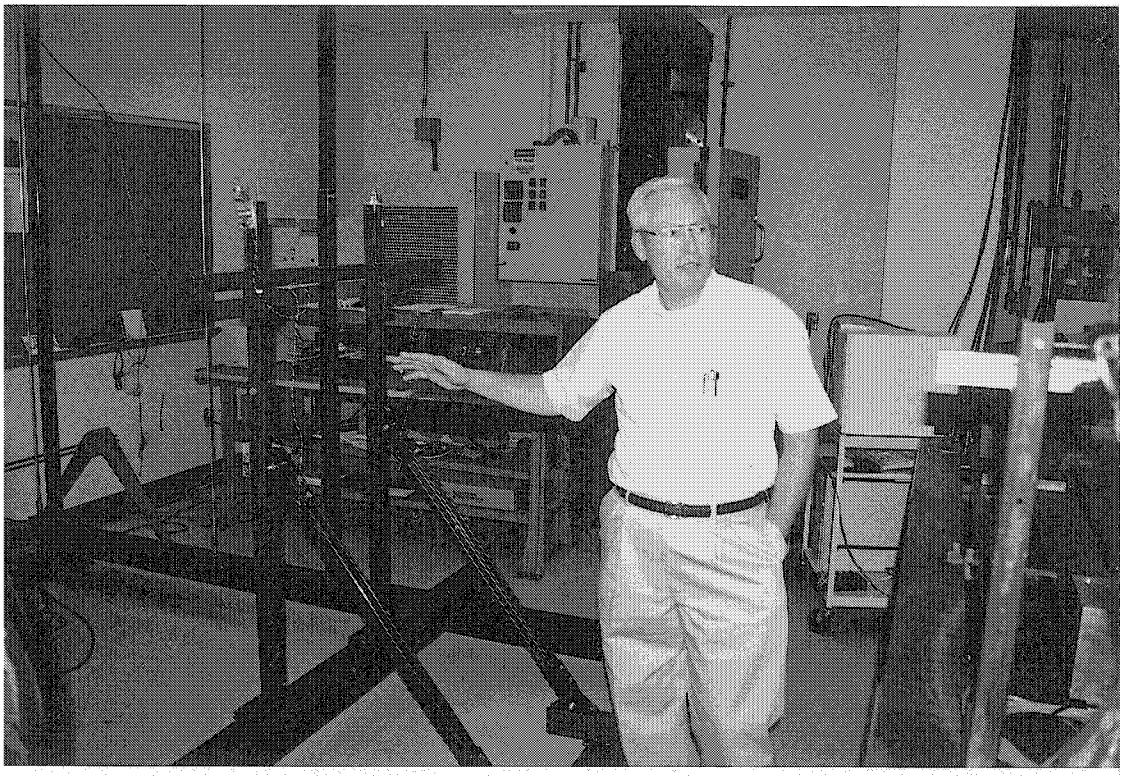


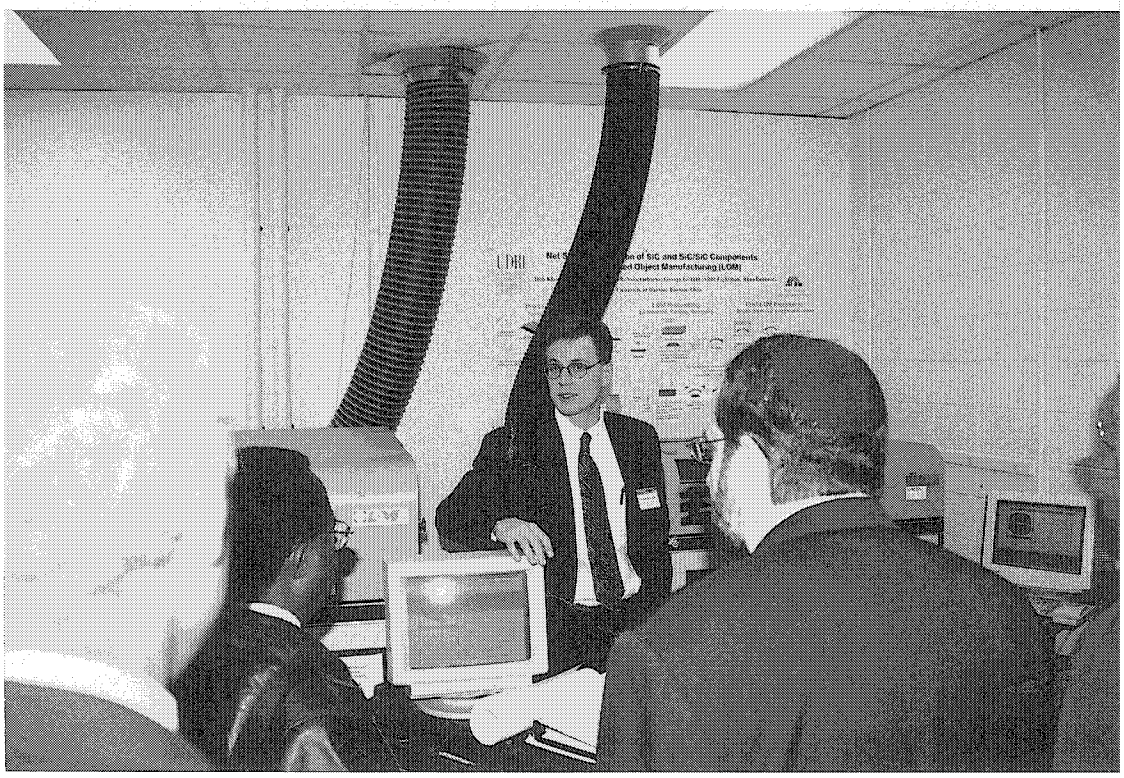
Jim Gardner and Bob Berrettini


The Center for
Kitty Hawk Project
11 01 '00


11 01 '00

University of Dayton

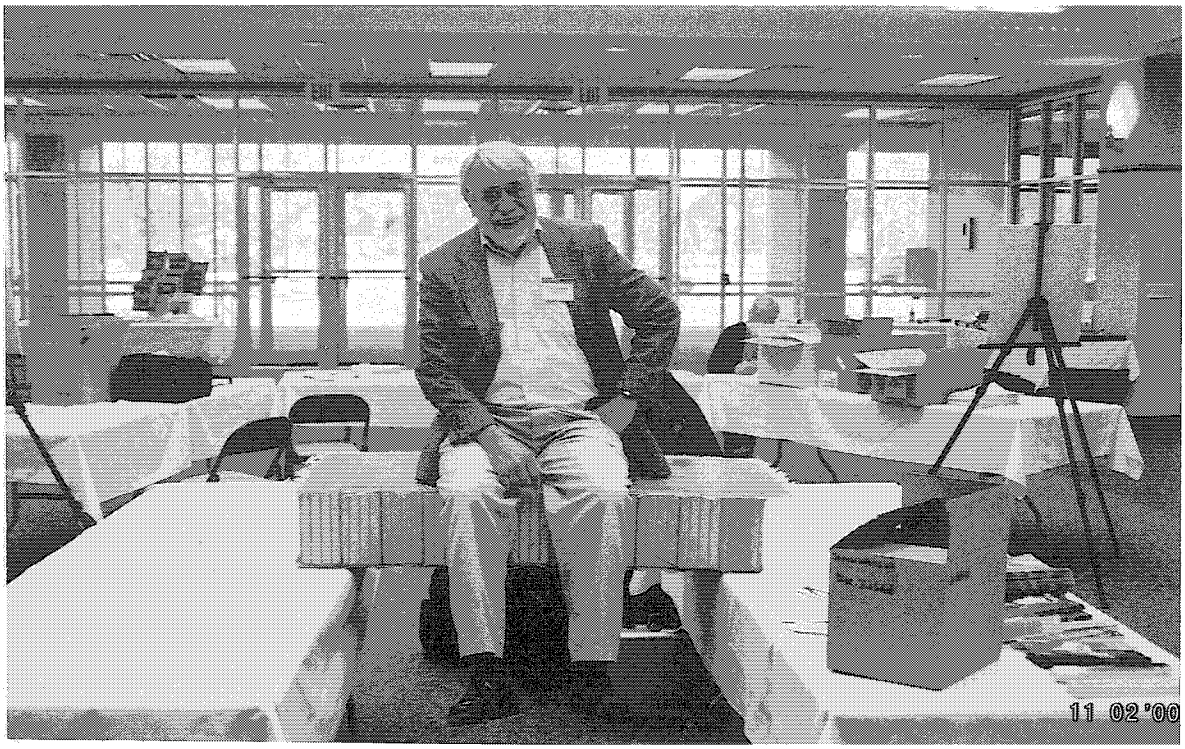




BRIDGE BUILDING

Al McKenney and Alan Karplus

BRIDGE BUILDING
(concluded)



Al McKenney

MINI WORKSHOPS

PROGRAMMABLE POWDER PREFORM PROCESS

Demonstration - hands-on project. A review of the process for producing high volume, net shape preforms for structural composites at the National Composite Center

Presented by Mike Melton, Scott Reeve, Correen Schneider
National Composite Center

COMPOSITE MATERIALS LABORATORIES

Characterization, properties testing, electron beam curing, and rapid Prototyping of complex-shaped composite at University of Dayton Research Institute Composite Research Facility

Presented by Dennis Gerdeman
University of Dayton

VIRTUAL ENGINEERING

Overview of the range of virtual engineering tools and processes employed by the AIM Center to improve manufacturing performance and productivity at the AIM Center

Presented by Michael Freed
The Advanced Integrated Manufacturing Center

COMPOSITES LAY-UP AND TESTING AT THE AIR FORCE RESEARCH LABORATORY

Hands-on composite fabrication, characterization, and testing at the Materials and Manufacturing Directorate of the Air Force Research Laboratory

Presented by Katie E. G. Thorpe
AFRL/MLBC Wright-Patterson Air Force Base

VACUUM ASSISTED RESIN TRANSFER MOLDING (VARTM) FOR FABRICATION OF BRIDGE DECKS AND OTHER STRUCTURAL APPLICATIONS

A demonstration of the composite bridge deck construction program in Ohio

Presented by Mark Murton
National Composite Center

EDUCATIONAL OUTREACH AT WRIGHT-PATTERSON AIR FORCE BASE

Kathy Schweinfurth

Wright-Patterson Air Force Base
Educational Outreach Office Coordinator
Area B., Bldg. 45, Room 01
Wright-Patterson Air Force Base, Ohio 45433

Telephone: 937-255-0692
e-mail Kathleen.Schweinfurth@wpafb.af.mil

Kathy Schweinfurth

Educational Outreach at Wright-Patterson AFB

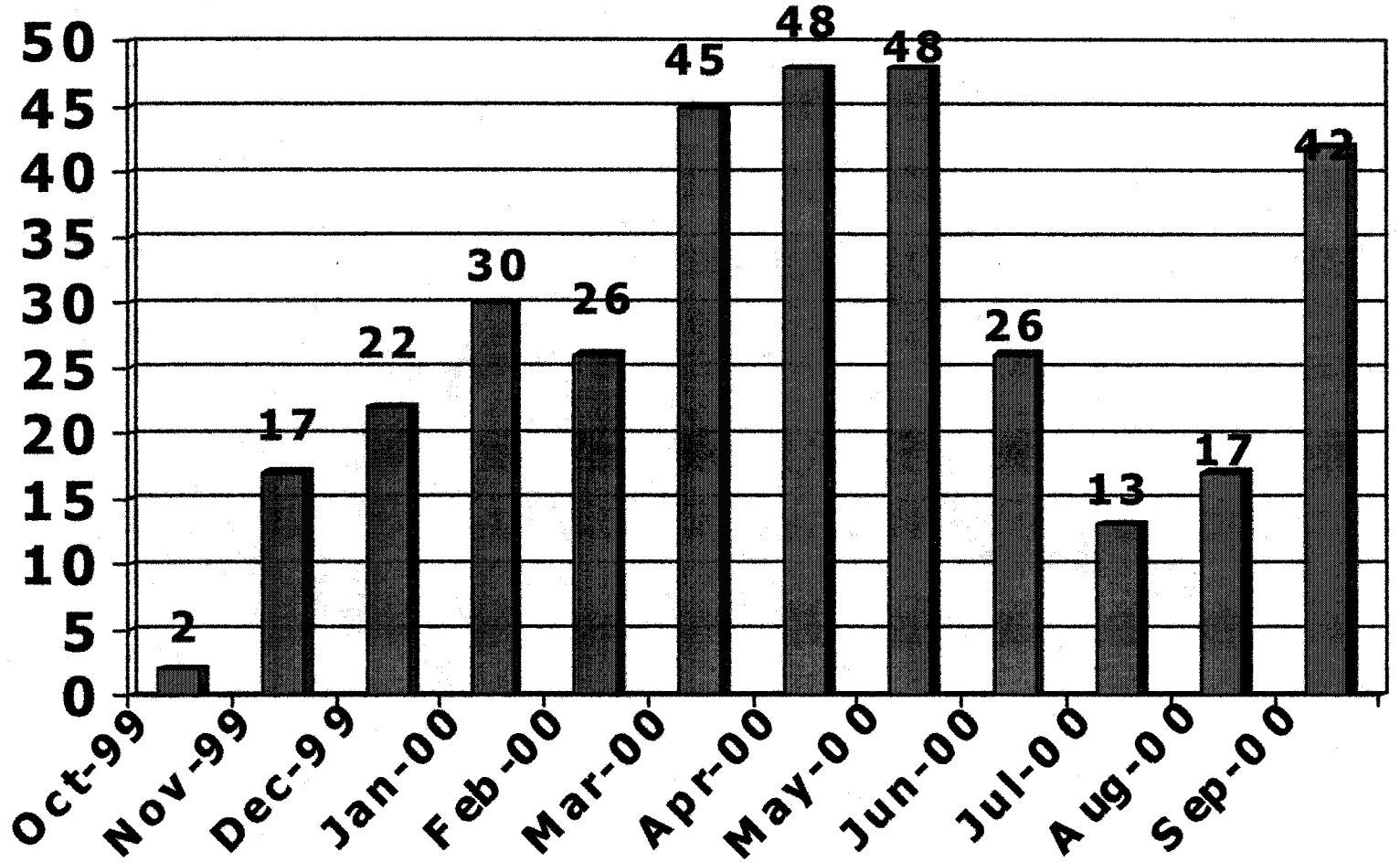
Kathy Schweinfurth,
Coordinator, WPAFB Educational Outreach Office
October 2000

Why Did We Need Educational Outreach At WPAFB?

- Many Base Educational Outreach Activities, but Programs Were Corporately Disjointed
  - No Coordinated Effort
  - No Single POC for Schools Seeking Support From WPAFB
- We Need to "Grow" Future Personnel
- Increasing Demand for WPAFB Involvement in Regional and Statewide Educational Activities

Is There A Need?

Industry/Business Say "Yes"
Our Data Says "Yes"



Support Requests = 336 (As of 30 Sep 00)

First Steps

- **ASC and AFRL Partnered to Form the WPAFB Educational Outreach Office in Jan 99**
  - **Make It Easy for Education Community to Make Contact With WPAFB**
  - **Make it Easy for WPAFB Community to Volunteer to Help Schools**

- **Excellent Community Relations Effort With A Little Selfish Intent**
  - **Be a Good Neighbor ... *and* To Interest and Excite Students in Future Careers at WPAFB**

What Do You Need to Set Up An Educational Outreach Program?

- Top Level Support
- Dedicated Resources
  - People
  - Funding
- People Who Know Education
  - Teachers On-Staff ...or As Consultants
  - People Who Can Translate Your Capabilities to Educational Standards, Curriculum and Needs
- A Way to Communicate
- Excitement and Enthusiasm
- Willingness to Share with Community

How Do You Get Started?

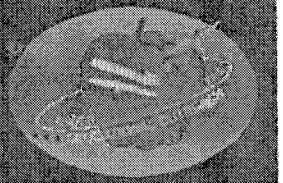
- **Have A Specific Organization Coordinate the Effort**
  - Make It Easy For Others to Volunteer Their Time
- **Find Out What Your Local Schools Need**
  - Talk with Administrators/Teachers
  - Talk with Employees Who Are Parents
- **Match Their Needs to Your Capabilities**
  - Offer Your Services - Be A Resource!
    - Classroom/Career Day Speakers
    - Volunteers
    - Programs

The First Year

- Established WPAFB Program Framework
  - Executive Board and Working Group
  - Strategic Plan / Review & Compilation of Existing Programs
- Set-Up Shop - Total Office Renovation
- Program Awareness / PR / Open House
- Customer Survey, Mailing List, Data Base
- Determined Program Priorities
  - Existing, Old, New
- Began Participation in Community Events as Base Activity
- Began Gathering Data

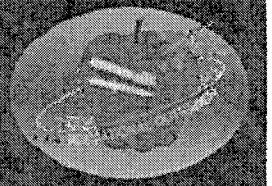
Mission and Vision

Mission



The Mission of the Wright-Patterson Air Force Base Educational Outreach Office is to Facilitate Partnerships With the K-12 Educational Community to Increase Student Awareness and Excitement in All Fields of Math, Science, Aviation and Aerospace.

Vision



The Wright-Patterson Air Force Base Educational Outreach Office Will Become a Science Information Clearinghouse Which Will Encourage and Enhance Science and Math Education Throughout the United States (...the World...and Beyond!!)

Educational Outreach Goals

Match WPAFB Technology, Resources, Expertise With Student & Educational Community Needs To:

- Increase Students' Academic Performance & Enthusiasm for Learning
- Help Teachers & Schools Become More Effective
- Be an Agent of Change for Educational Systems

Increase the Effectiveness of WPAFB Educational Outreach Programs by Providing a Base-wide Support System and Framework

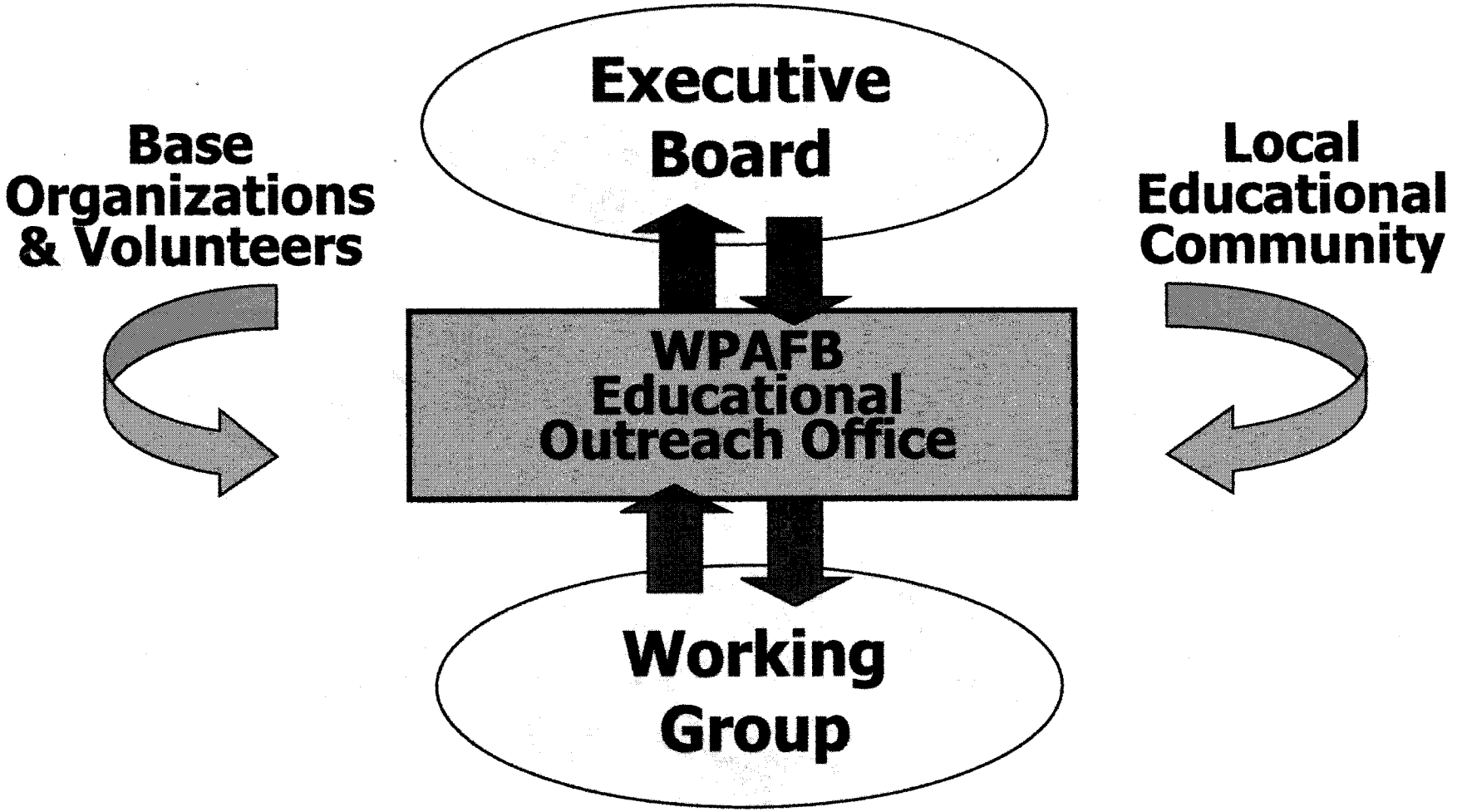
Optimize and Reward WPAFB Employee / Personnel Support / Participation in Educational Outreach Activities

- Facilitate Individual Involvement by Providing a Variety of Opportunities for Service
- Advertise Opportunities and Successes

Keep Base Leaders Informed of and Involved in Educational Outreach Efforts

(And Have Fun!)

Organizational Framework



What Do You Need To Do To Be Effective?

- Provide a "Complete Package" for Teachers
  - Pre/Post Activities
  - Mentors
  - Continued Involvement
  - Specific Point-of-Contact
- Be a Resource
- Partner With Other Organizations In Area
- Provide Continuing Programs
  - Allows Students to Stay Involved and Interested
  - Allows Students and Teachers to Continue to Learn
    - Promotes Systemic Change

Affiliations

- Miami Valley Interactive Distance Learning Consortium
- Fairborn Improvement Task Force
- National Teachers Training Institute
- DOD Science, Math and Engineering
- Ohio Business Roundtable Visioning Committee
- Ohio Math and Science Coalition
- Experimental Aircraft Association
- Wright STEPP
- Boy and Girl Scouts
- Ohio Space Grant Consortium
- American Institute of Aeronautics and Astronautics
- Local Science Fairs
- Super Saturday

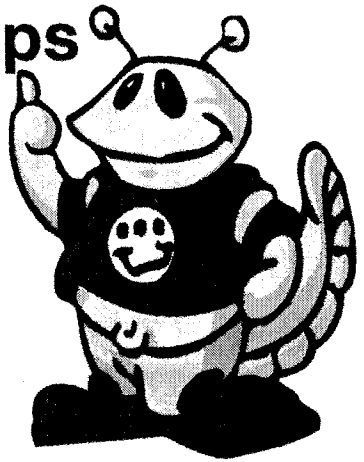
....And More!!!

What Is The Impact?
(First Year Data)

Program	Schools	Students
Wizards of Wright	34	3800+
Project MISSE	14	300+
SEMEDS	35	2000+
TECH TREK	30	5000+
MV READS	All Miami Valley	TBD
Wright Connection	TBD	TBD
Robotics	25+	Infinite
MVIDL	All Miami Valley	TBD
Tours	TBD	TBD
Mentor/Shadows	TBD	TBD
Inventing Flight	Nation/World-Wide	
Totals	140	14,000+

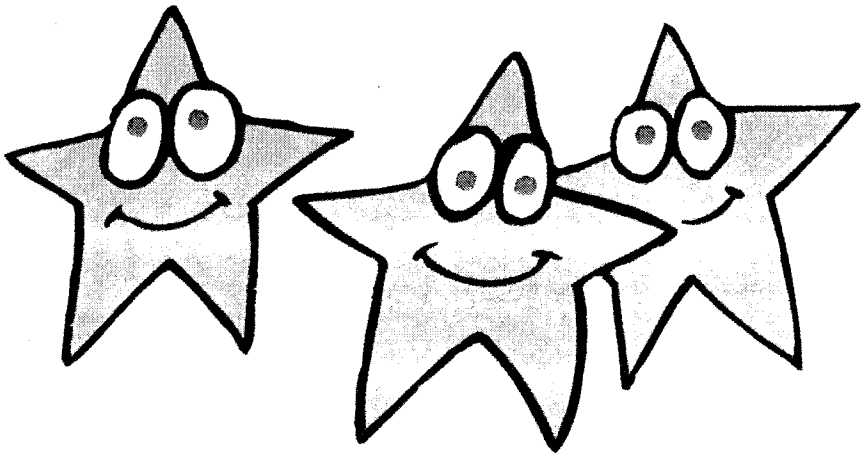
What's Next?

- Web-Site Up and Running
- Distance Learning Capability (MVIDL)
- Develop In-House Teacher Program
- Tech Trek II?
- Grow Programs/Document Activities
- Establish and Formalize Partnerships
  Volunteer Management
- Explore Funding Alternatives
- Have Fun!!



Why Do Outreach?

- **It is Part of Our Mission (Especially in AFRL)**
  - **Public Law 101-510**
  - **Title 10, Part 2194 (Educational Partnerships)**
- **Excellent Community Relations and Recruiting Tool**
- **What We Can Do - Make It Easy For People To Become Involved By Setting Up An Effective and Exciting Coordinated Program That Benefits the Future Of The USAF**



Educational Outreach Helps Us Groom the Scientists and Engineers of the Future!!

Kathy Schweinfurth,
WPAFB Educational Outreach Office
(937) 255-0692
email: kathleen.schweinfurth@wpafb.af.mil

PROGRAMMABLE POWDER PREFORM PROCESS (P4)

Correen Schneider

National Composite Center
2000 Composite Drive
Kettering, Ohio 45420

Telephone: 937-297-9521
e-mail cschneider@compositecenter.org

Correen Schneider

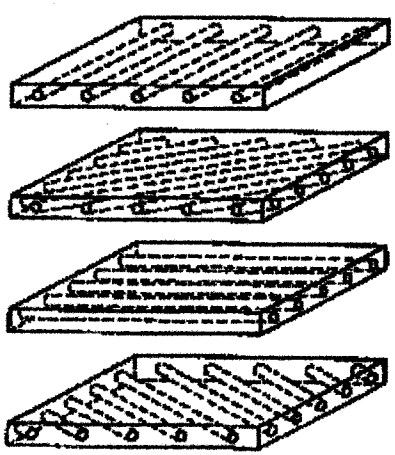
Strive for High Volume Low Cost Composites

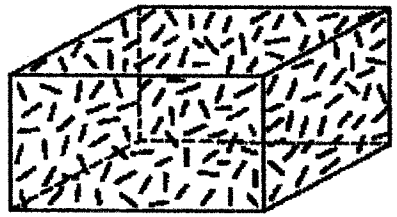
Programmable Powder Preform Process (P4)

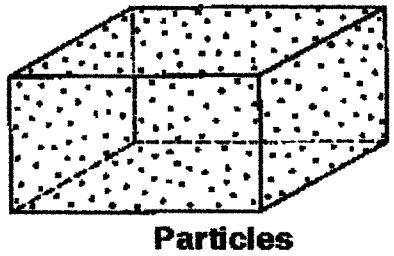
Correen A. Schneider
National Composites Center

Composites

- A composite consists of two or more materials to achieve certain characteristics and to maximize specific performance properties.







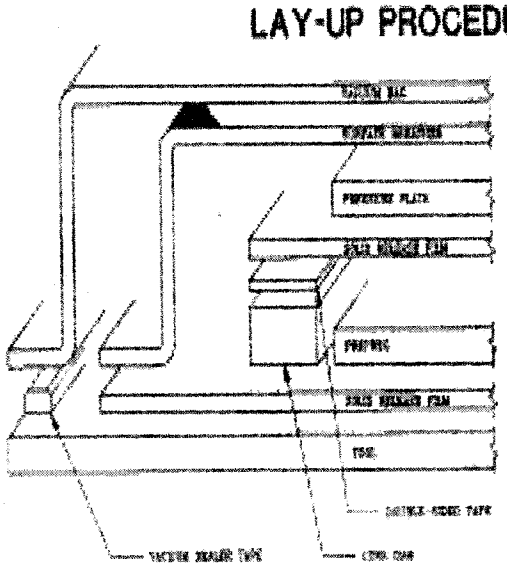
- Composite can be any combination of fibers, whiskers and/or particles embedded in a common matrix.

Why Composites ?

- Compared to metals, composites are:
  - –stronger and stiffer
  - –lighter
- Can tailor strength and stiffness
- Can consolidate parts
  - –unitized design
  - –reduced assembly costs

Existing Composite Processes

- High Quality, High Cost, High Performance
- Hand lay-up of prepreg; Cure in Autoclave
- Aircraft and Recreational



FIBERITE®

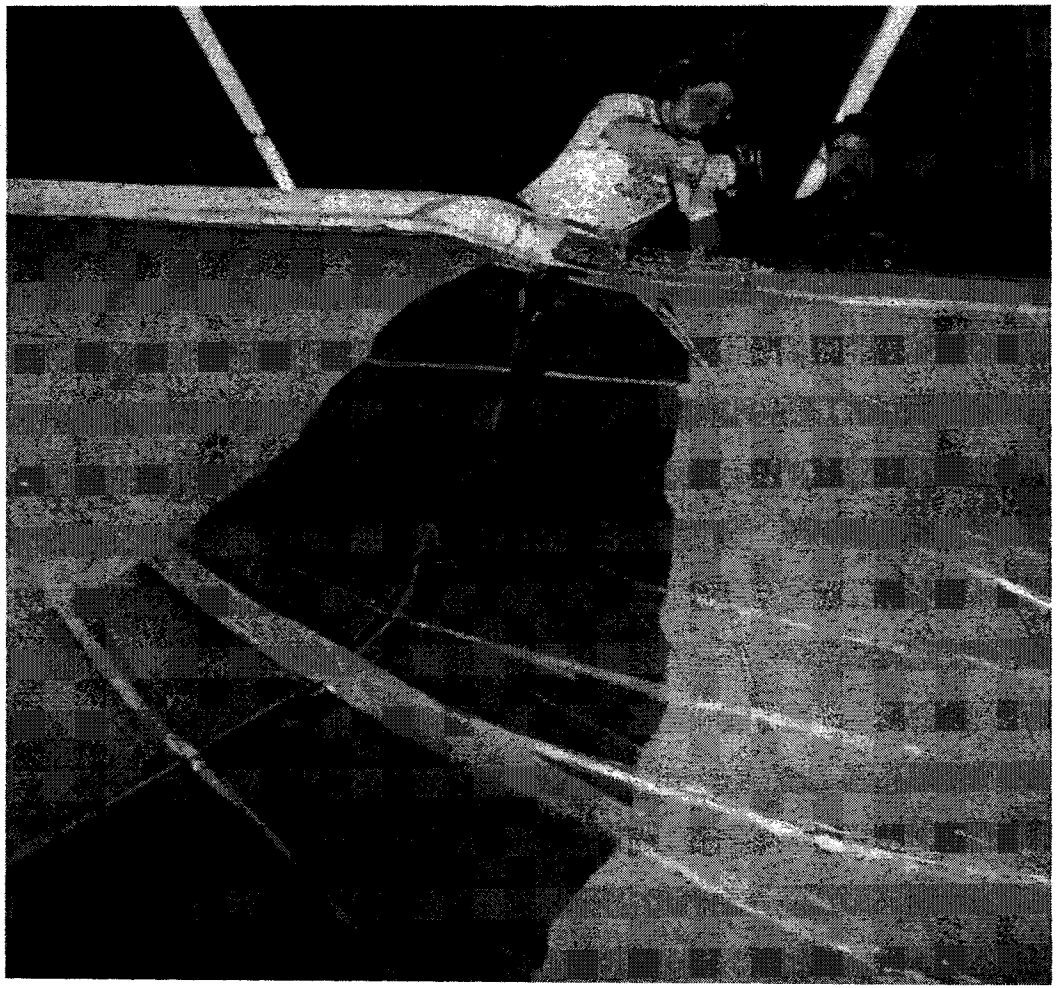
Existing Composite Processes

- Low Cost, Low Quality, Low Performance

- Spray up of chopped fibers & resin
- Boats, Shower/Tub, Stadium Seats

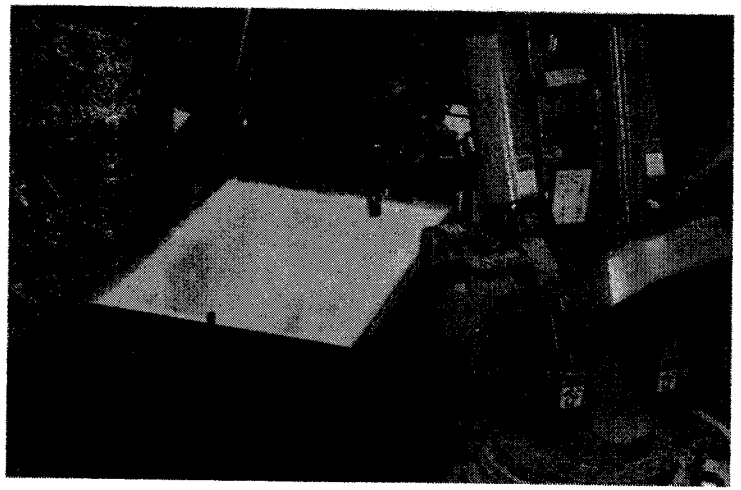
Next Evolution

- Hand lay-up of dry fiber
- Resin Infused
  - Resin Transfer Molding (RTM)
  - Vacuum Assisted RTM (VARTM)



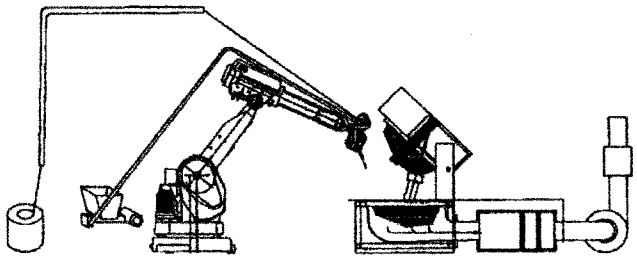
Programmable Powdered Preform Process (P4)

- Fully automated process for chopping and spraying fiber
- Rapid fabrication of fiber preforms
- Reduced assembly
- Potential net shape preforms
- Low material waste

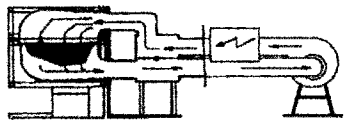


Programmable Powdered Preform Process (P4)

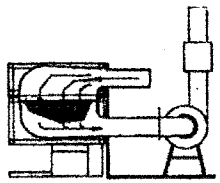
Glass Deposition:
Glass and Binder Applied to Screen via Robot Routines



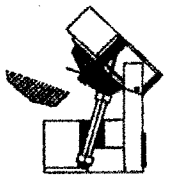
Consolidation:
Preform Compacted Hot Air Melts Binder



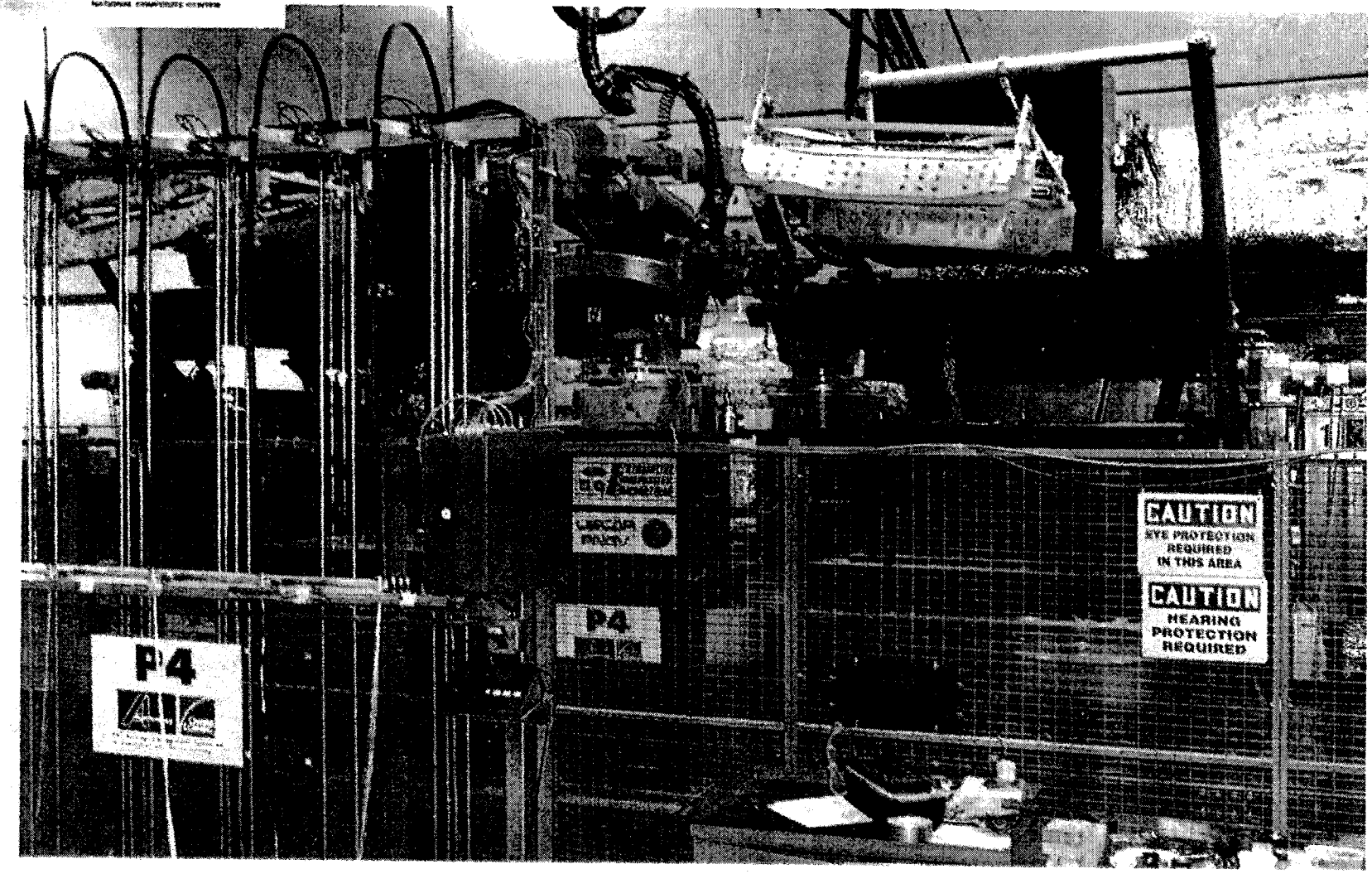
Consolidation:
Cold Air Freezes Binder and Sets Preform



De-molding:
Part Removed from Tool



P4 Manufacturing Cell



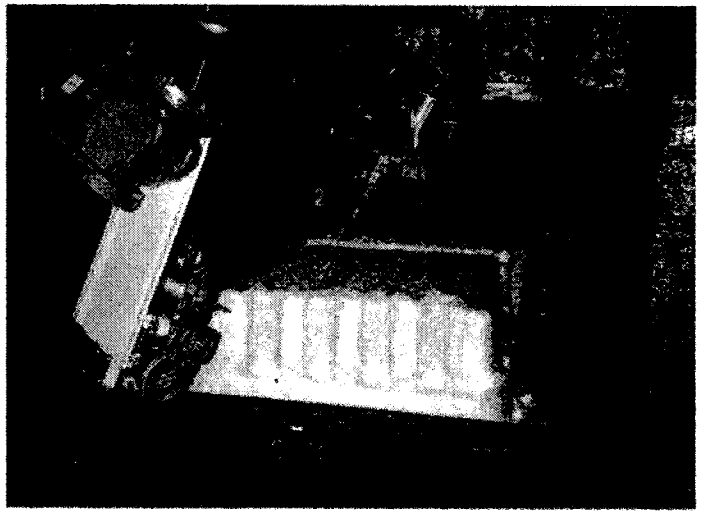
Programmable Powdered Preform Process (P4)

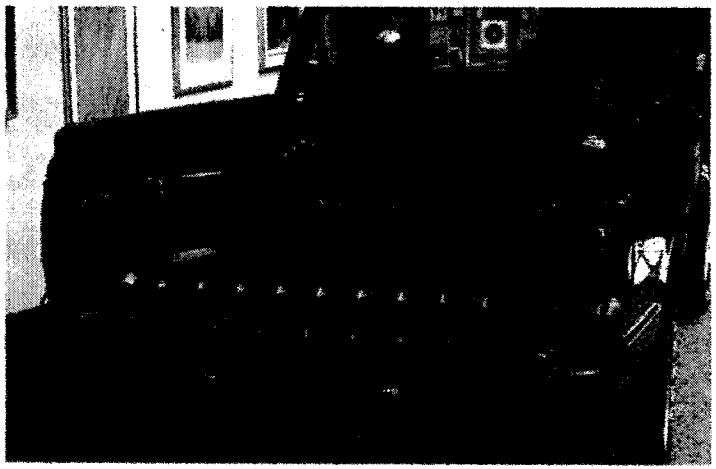
- Complex Geometries Possible
- Fiber Alignment Possible
- Extensive Design Flexibility
  - *"On the Fly"* Change of Fiber Length
  - *"On the Fly"* Change of Fiber Orientation
  - Continuous Variations in Thickness

  Incorporation of Rib Stiffeners, Openings, Sandwich Cores, etc.

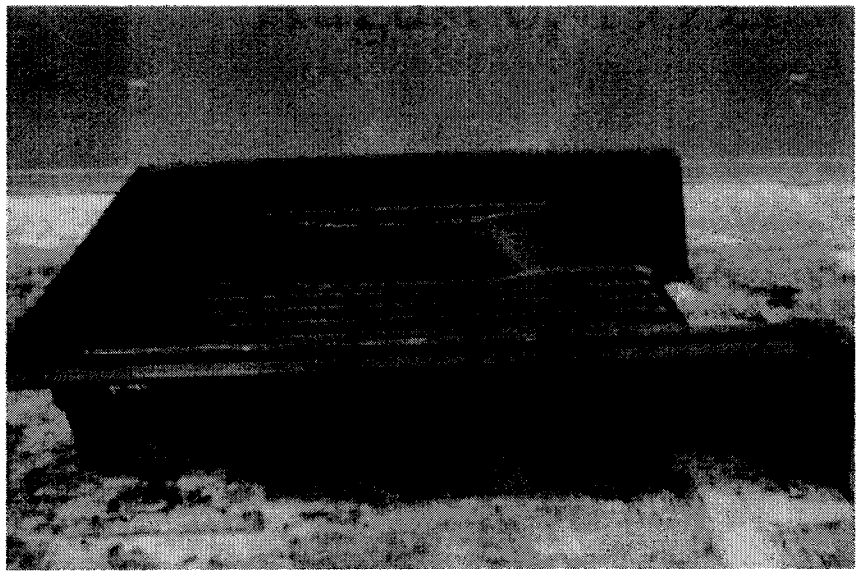
P4 Composite Pickup Truck Box

- Automotive Composites Consortium (ACC) Focal Project
- Fiberglass / Polyurethane
- Structure, not just Liner
- Performance Goal: 30% lighter than Conventional Steel + Liner
- Cost Goal: "Competitive" Rate
  - 4 Minutes to Produce Preform (P4)
  - 4 Minutes to Infuse (1000 ton SRIM Press)



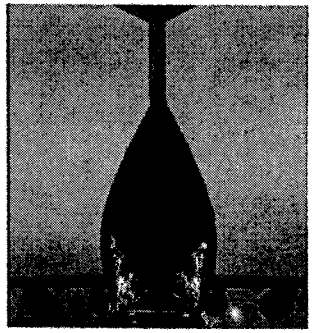


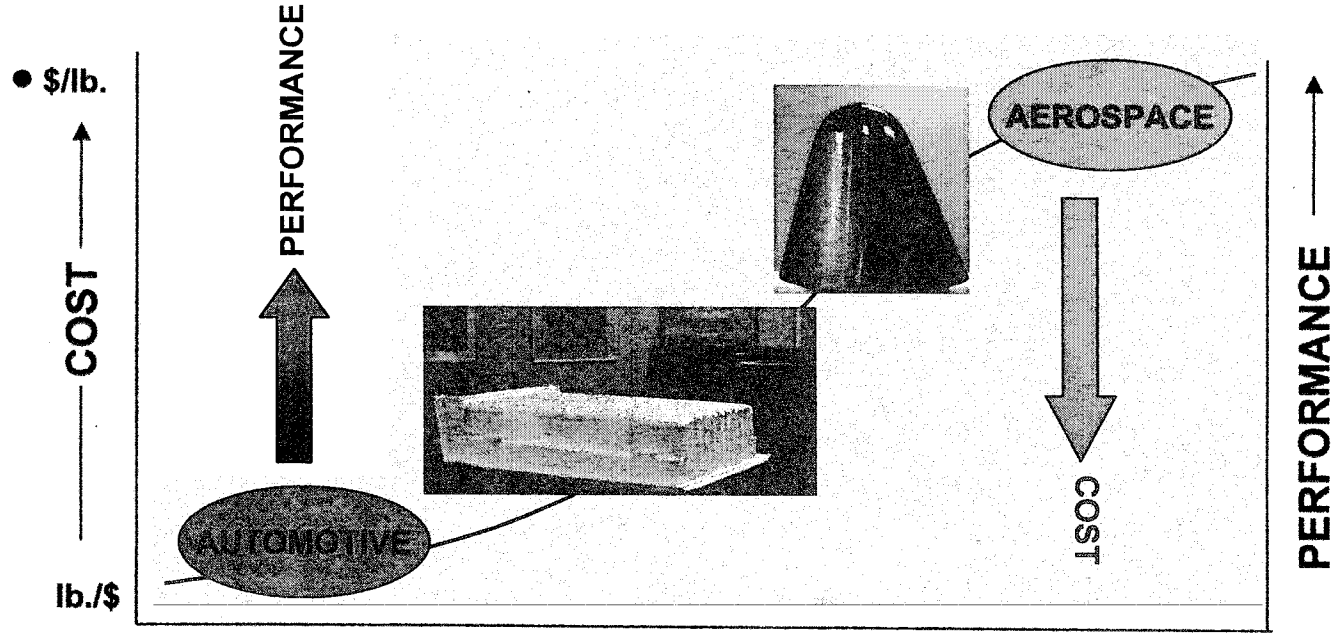
Pickup Truck Box Processing

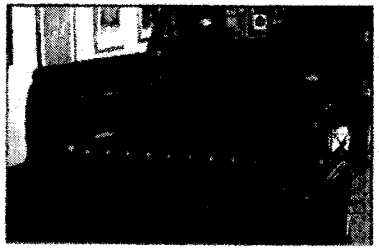


- Successfully completely filled truck box on August 6, 1999
- GM announced production in 2001 on Silverado
- Ford announced production on the Explorer

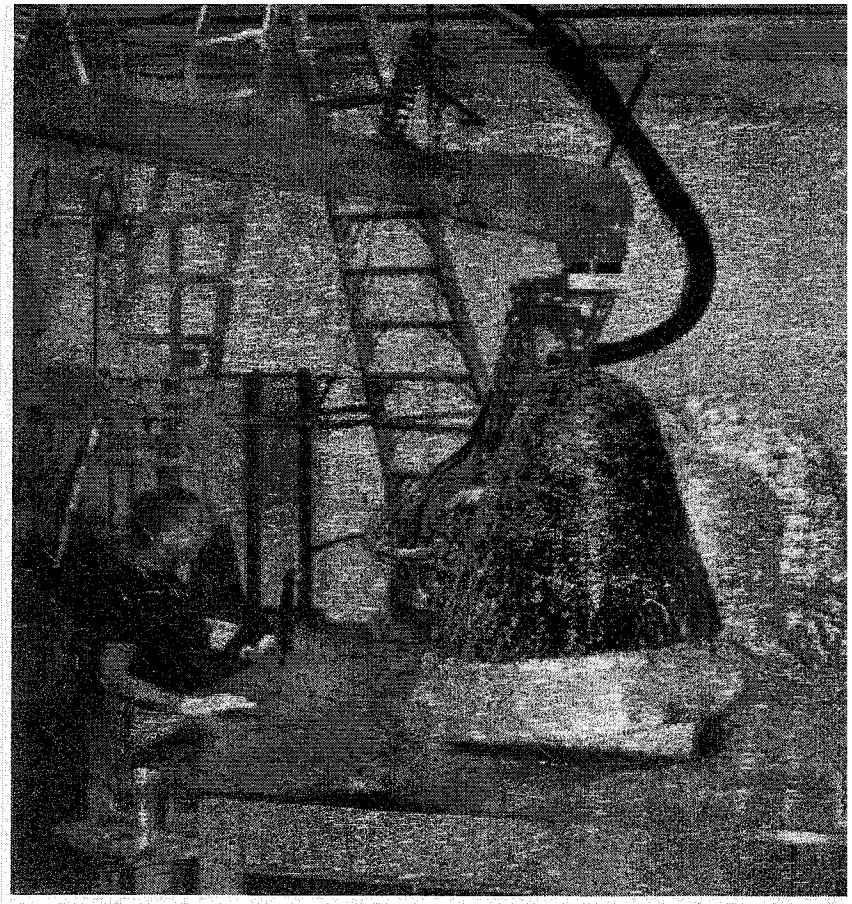
Cost vs Performance Compromise Differs for Different Industries





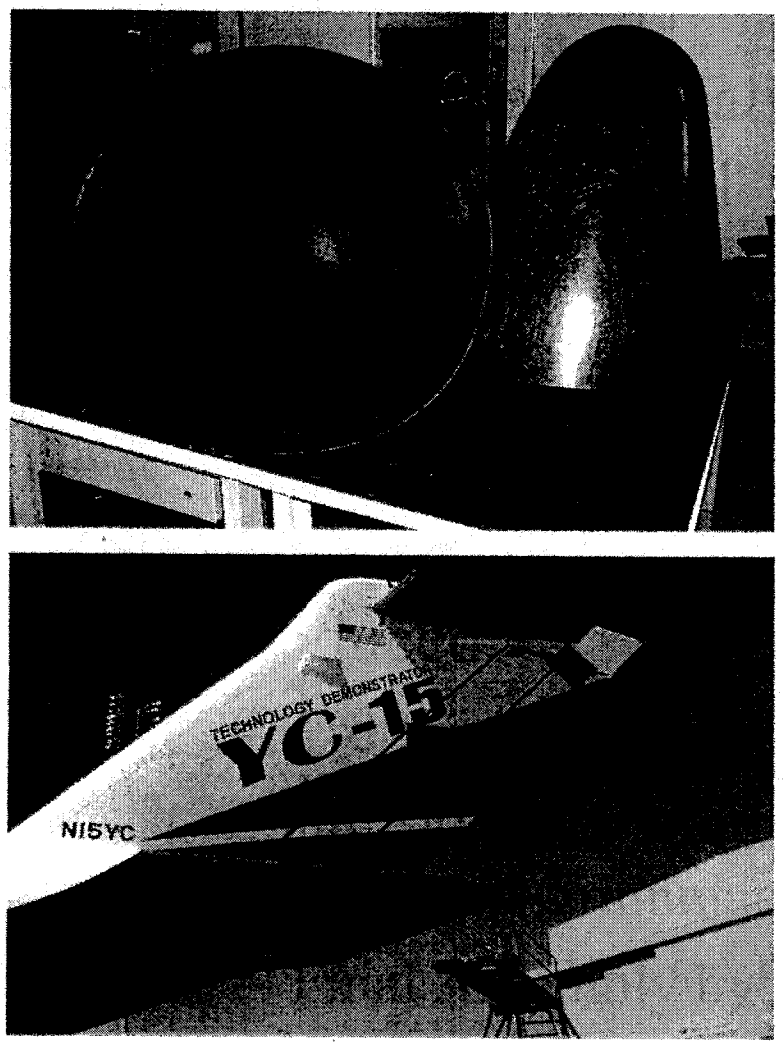


Programmable Powdered Preform Process for Aerospace (P4A)



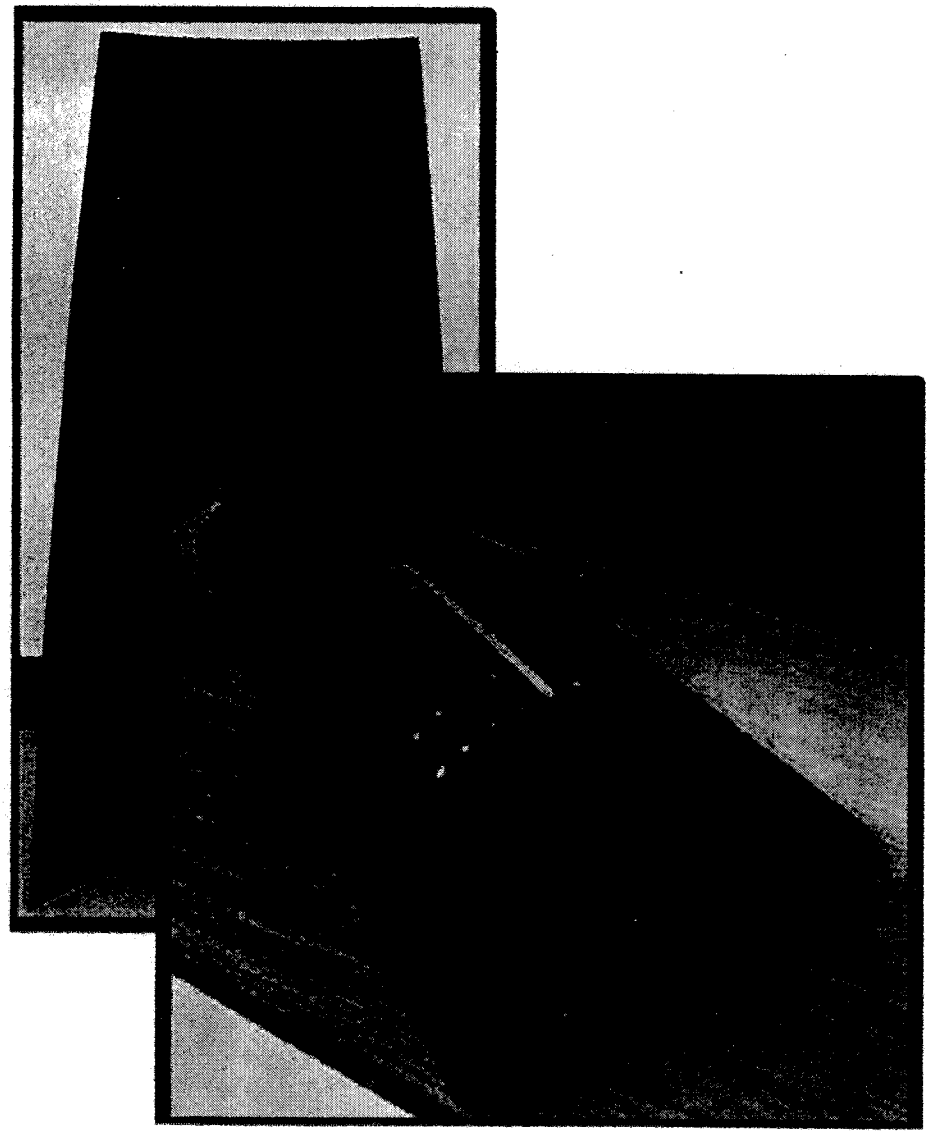
- Adapt Low Cost Automotive Process to Aerospace
- Aerospace Materials, Properties
  - Carbon Fibers, Aerospace Resins
  - Orientation
  - Goal: 90% Modulus, 80% Strength of Continuous PMC
- Complexities Representative of Aerospace Structures

YC-15 Tailcones Demonstration Parts



- Cost Modeling/Validation through Structural Demonstration Article
- 80% Less Expensive than Composite Counterpart
- 6 Full Scale Components Produced
  - Preforms Produced at NCC
  - Infusion of Preforms at Northrop Grumman
  - Final Assembly by Boeing

F - 18 Access Cover

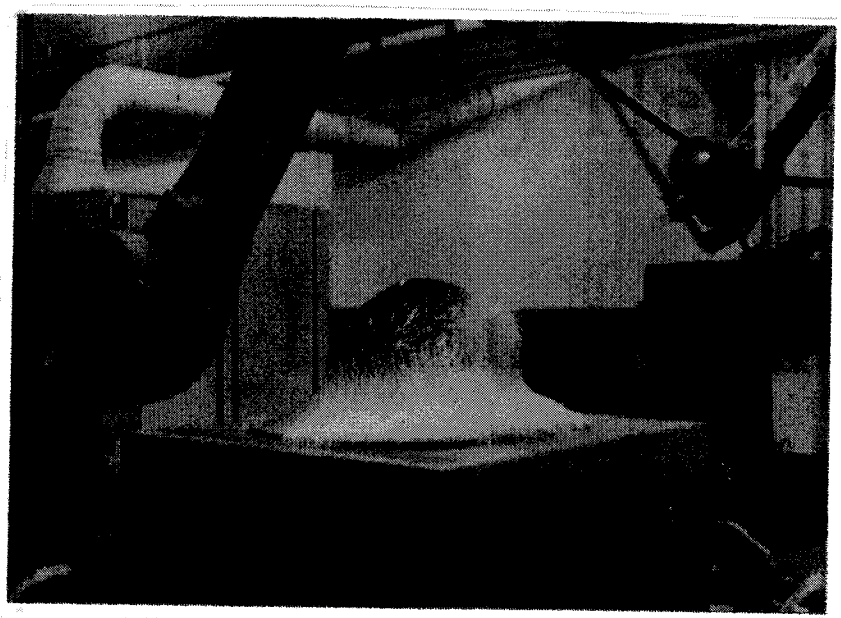


- **Existing Production Part**
  - Cost, Weight, FEA Model
  - Comparison Opportunity

- **Demonstration of Enabling Technology for Beaded Structure**

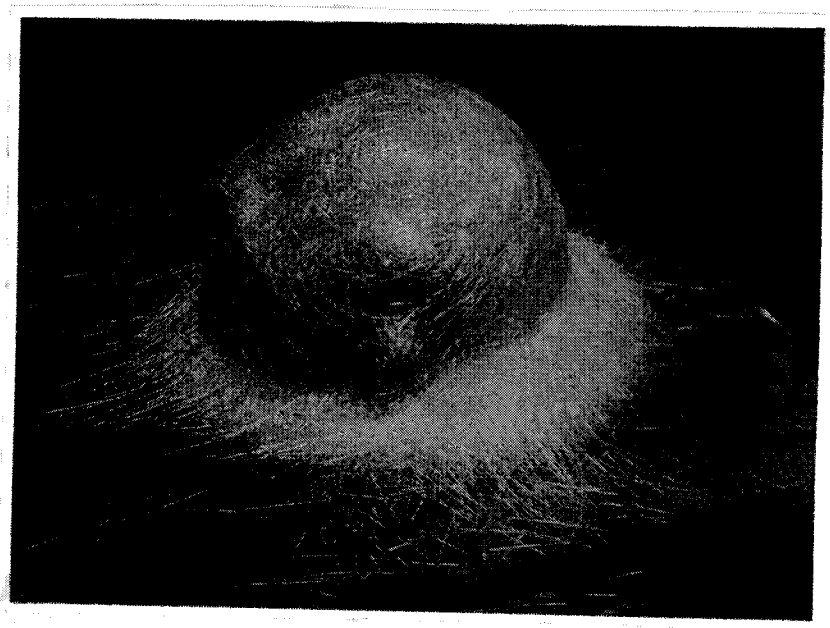
- **46% Cost Savings**
  - Non-autoclave/VARTM
  - P4A
- **9% Weight Savings**
  - Fastener Elimination
  - Hat Stiffener Build Elimination

Commercial Applications

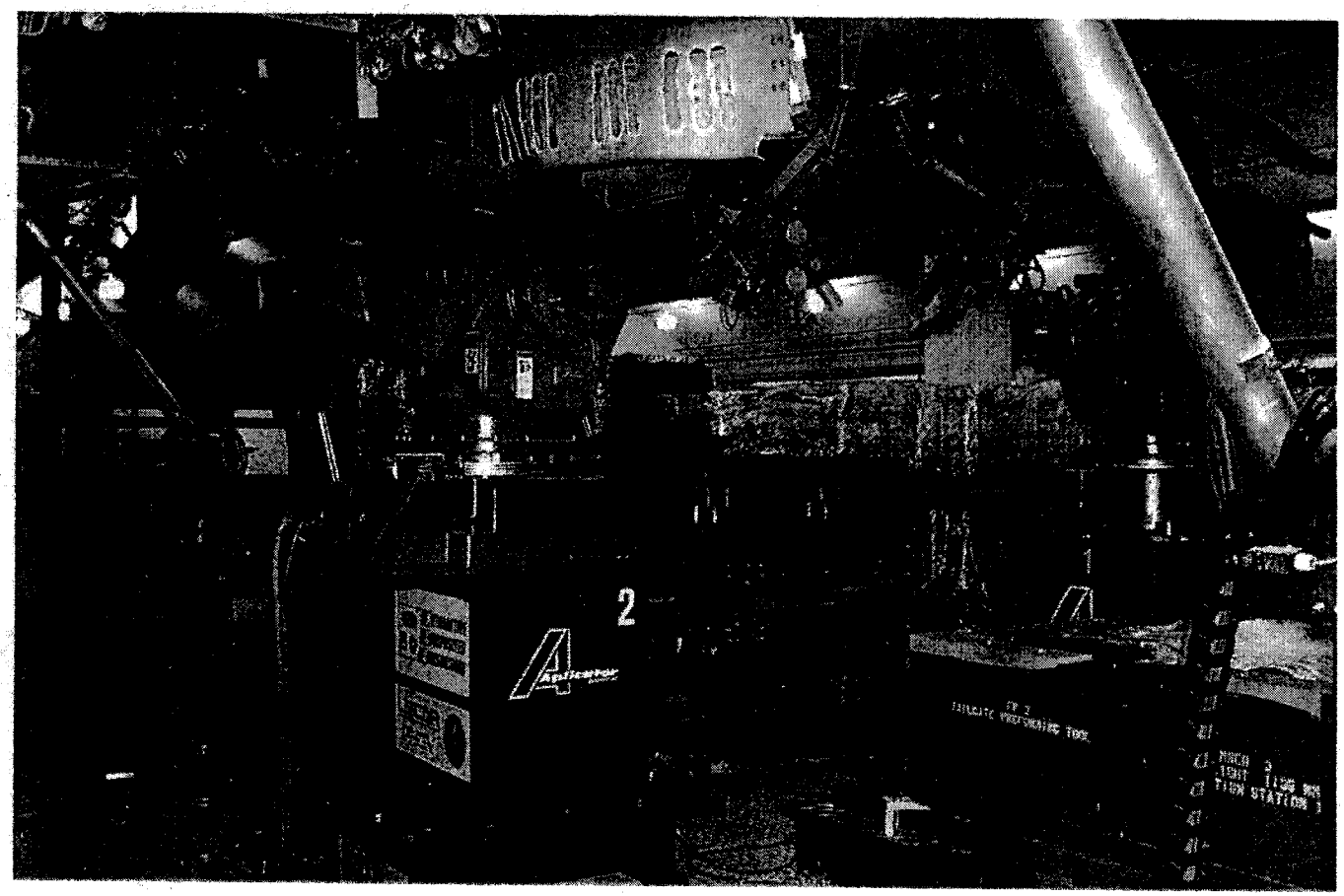


- Armor Vehicles
- Bridge Decks

- Safety Helmets
- Boating Industry



VIDEO on P4 Process



Questions ???

EXPERIMENTS IN LIQUID CRYSTALS: DIFFERENT STATES AND DEVICES

James V. Masi

Director
Northeast Center for Telecommunications Technologies
One Federal Street
Springfield, Massachusetts 01105

Telephone 413-731-3155
e-mail masij@email.msn.com

James V. Masi

Experiments in Liquid Crystals: Different States and Devices

James V. Masi
Northeast Center for Telecommunications Technologies
Springfield, MA 01105
(413)731-3155, FAX (413)734-0515
masi@ stcc.mass.edu

Abstract:

A thermotropic liquid crystalline state occurs in certain materials, in a temperature region between the solid and liquid (isotropic) states. The material in this region possesses some properties of both liquids and solids. The anisotropies of this *liquid crystal* (L.C.) material gives it some of the most interesting, beautiful, and useful devices, challenged only by nature itself.

This set of five experiments shows the electrical, thermal, magnetic, optical, and mechanical properties and anomalies responsible for the useful effects and devices resultant from these materials. From soap to thermometers, from displays to filters, from acoustic to non-linear devices, liquid crystals and the experiments one can easily do will make this experience a useful and entertaining one. Demonstrations, hands-on tests, and samples will be included in these experiments

Key Words: Liquid crystals, displays, thermotropic, nematic, liquid crystal polymers.

Prerequisite Knowledge: The student should be familiar with the basics of materials science, metallography, and chemistry. Levels at which these experiments are performed are second semester junior year and either semester senior year. The students are first given lectures the properties of materials including organic liquid crystals and polymer liquid crystals (PLCs). They should have already had a laboratory experiment on metallography and sample preparation.

Objectives: The objectives of these experiments are to show how the unique properties of liquid crystals lend themselves to applications involving thermal, electrical, magnetic, and optical properties and how they are incorporated in a variety of devices. These experiments contain all of the elements of good design, with the caveat that a novelty in structure is sometimes a part of design. The students learn the process of designing materials for the world of telecommunications, analyze those already used, and suggest possible solutions to the problems involved with present technology.

Equipment and Supplies:

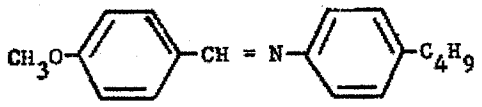
(1) Metallurgical preparation and polishing apparatus (eg. Buehler Co., Port Washington, NY).
(2) Varieties of liquid crystal chemicals (Roche Chemical Div., Hoffmann-LaRoche Inc., Nutley, NJ; Baker Chemical, Licristal Materials.)
(3) Low voltage 60Hz power supply, Polarizers, ¼ wave plates (Edmund Scientific)

(4) Miscellaneous graduates, glassware, ovens (Fisher Scientific),
(5) Indium-tin oxide coated glass and plastic (Tecknit Corp., Cranford, NJ)
(6) Miscellaneous meters and power supplies.
(7) Metallurgical microscope (Olympus, Zeiss, etc.).
(8) Liquid crystal displays (LCD Planar Optics, Farmingdale, NY)

Introduction:

Liquid Crystal Materials

In the process of forming crystalline solids, organic materials (anthracene, camphor, etc.) exhibit long range ordering. Their molecular centers are set on a repetitive lattice. These molecules also have a definable orientation with respect to the rest of the lattice. Usually, when compounds such as these melt, they form an isotropic liquid, losing most of their long range (over two molecules) order and, in large part, any of their orientation properties that they had as a solid. Less than 0.5% of all organic compounds have a range of temperatures and conditions where they exhibit an state which is intermediate to the crystalline solid and the isotropic liquid. This state is called their "*liquid crystal*" state. Long-range order is maintained for a range of temperatures below the melting point. Compounds such as MBBA (p-methoxybenzilidene p-butyl aniline, an early Schiff Base material), shown in Figure 1, have alternate double and single bonds in a rigid, elongated structure and tend to form liquid crystals.



and cholesteryl acetate

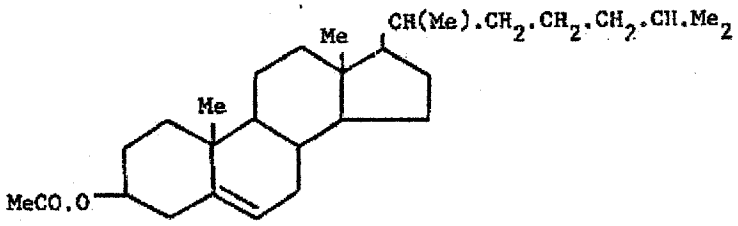


Figure 1. MBBA Liquid Crystal Material

This particular material, when mixed in eutectic composition with EBBA (p-ethoxybenzilidene p-butyl aniline) form an electrically active material which is a liquid crystal over a range of 0 ^{o}C to 55 ^{o}C . When an electric field is applied across these materials, they change from clear to milky white. These are called dynamic scattering materials (named after the hydrodynamic turbulence caused by the electric field influence). The resultant properties of these materials and other liquid crystal materials in other classes, such as esters and biphenyls, are quite unusual. The unique properties and the control of the chemistry leading to these properties make these methods excellent teaching and learning tools. A typical schematic of liquid crystal types is shown in Figure 2. At Western New England College and the Northeast Center for Telecommunications Technologies, laboratories have been developed involving four distinct

properties (and chemicals) of liquid crystal materials[1]. An overview of liquid crystal materials and properties[2] is given in the Appendix for use as a pre-lab lecture or as reference for the student and laboratory instructor.

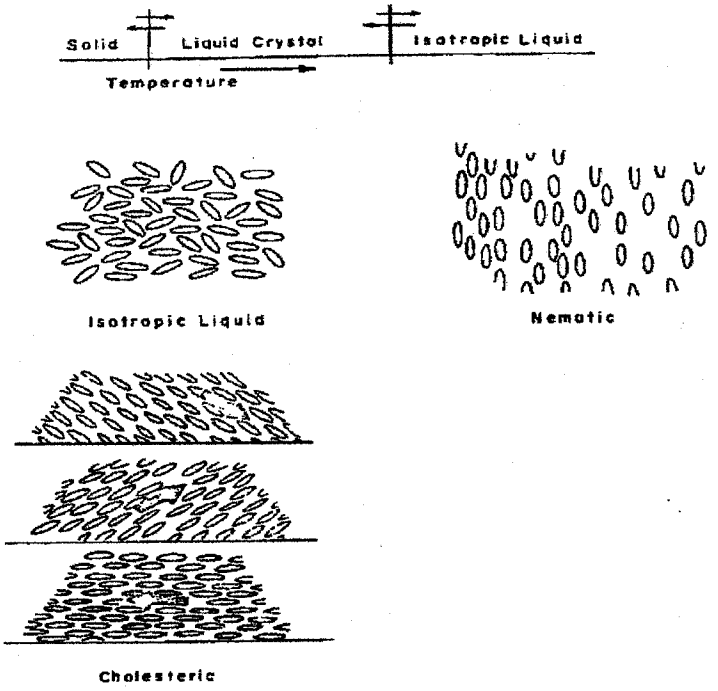


Figure 2. Types of Liquid Crystals and Temperature dependence

Procedure:

The specific aims of these experiments are to classify the mechanisms of liquid crystal chemistry, optical electric, thermal, and magnetic properties and devices, and to compare the results with theory. There are four experiments that the student should perform. The first is the observation of dynamic scattering in liquid crystals[1]; the second is a cholesteric color temperature indicating cell; the third is the fabrication and test of a liquid crystal light valve; and the fourth is a color cell produced by using polarization and quarter wave interference[1].

Experiment 1: Observation of Dynamic Scattering in Liquid Crystal Cells

In the dynamic scattering cell, there is no need for "anchoring" the molecules on either side of the ITO (indium tin oxide) coated glass (see experiment 3). The fabrication procedure is simple, consisting in obtaining indium tin oxide coated glass plates (e.g. Tecknit Corp), Mylar spacers, and epoxy sealers (Figure 3).

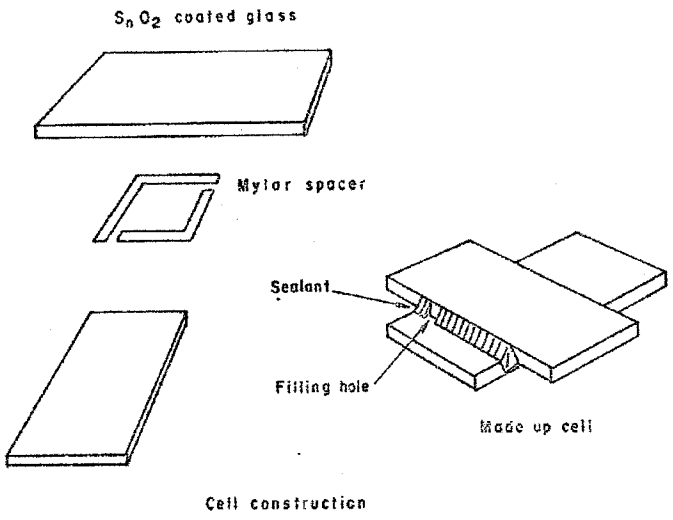


Figure 3. Schematic representation of cell construction

Once the cell is filled with the dynamic scattering liquid crystal material and the cell is sealed (see Appendix), the cell is ready for observation and test.

1. Place one of the metered a.c. supply terminals on one of the extended ITO electrodes, and place the other on the electrode of the opposite ITO coated glass.
2. Observe both macroscopically and microscopically, noting visibility vs angle of view.
3. Take observations (photometric if available) and measure either backscatter from ambient or transmitted light vs voltage. Plot Transmission vs voltage (RMS).
4. The observations are taken to the point where hydronamic turbulence occurs.
5. Observations should correspond roughly to those shown in the Appendix.

Experiment 2. Cholesteric temperature indicating cell

This experiment shows the pitch change of the cholesteric L.C. with temperature.

1. Take a clean piece of white polypropylene or polyester plastic (approximately 2 cm. x 4 cm. x 1 mm.) and a piece of clear polyester of the same size.
2. Place a drop of a cholesteric L.C. (e.g. cholesterol nonanoate) onto the white plastic in the center.
3. Take the clear polyester and place it onto the white plastic with the L.C. and seal the edges, making sure to press the L.C. material to a uniform thickness.
4. Take the sealed cell and place it onto a large aluminum block (10 cm. x 10 cm.) along with a surface thermometer (Fisher Scientific) and register the temperature of the block vs. the color of the cholesteric liquid crystal sandwich.
5. Discuss the construction of a wide temperature range L.C. thermometer.

Experiment 3. Fabrication and test of a nematic liquid crystal light valve

Fabrication of the nematic light valve involves the observation of birefringence change under the influence of an electric field (see Appendix).

1. Construct a light valve with nematic L.C. material as in experiment 1, with the added step of surface alignment on each side of the ITO coated glass (Appendix).
2. After sealing the cell, no macroscopic changes will be noted with the application of 2-4 volts d.c., due to the higher resistivity of the material and the fact that only the director (index of refraction) changes with field application.
3. Now place the cell onto a light table or place a light source behind the cell, and place a polarizer on either side of the cell, either parallel or perpendicular to each other's axis (Figure 4).

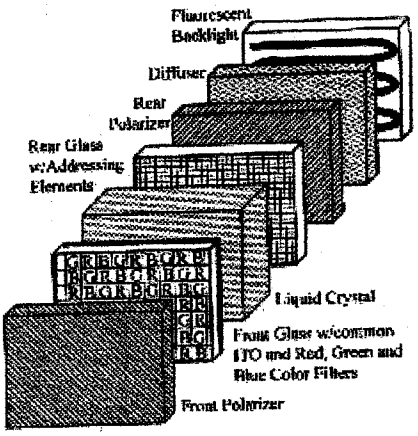


Figure 4. Nematic L.C. Cell

4. Measure transmission vs voltage and transmission vs frequency (signal generator) for this cell. Also measure transmission vs angle of view.
5. **Slowly** raise the temperature of the cell on a hot plate and observe the nematic to isotropic transition temperature. Allow it to cool and watch the reversal.

Experiment 4. Color nematic quarter wave interference cell

This experiment shows the other side of birefringence, namely color.
1. Take the cell made in experiment 3, along with its polarizers.
2. Place a quarter wave plate at 45 degrees to the polarizer optic axis on either side of the sandwich and place the assembly on the light table.
3. Turn the light valve "on" (i.e. 3-5 v.d.c.) and observe the color of the cell vs the angle of one of the quarter wave plates as it is rotated.
4. Explain the mechanism responsible for this phenomena.

Comments:

These experiments exhibit some of many possible electro-optic and magneto-optic effects in liquid crystals. They demonstrate how to obtain either scattering or birefringence changes, the latter giving optically observable effects when the cell is placed between polarizers.

Appendix: Liquid Crystals [2]

Anisotropy

Although the properties of its constituent molecules are usually anisotropic, a normal liquid exhibits isotropic behavior due to spatial and temporal averaging and best-fit charge

compensation. In a liquid crystal, orientational order exists over distances of many micrometers, and their macroscopic properties are anisotropic. Figure A1 shows the way in which molecules might be arranged in a normal liquid and in a liquid crystal. A preferred direction (or *director*) in a normal liquid does not exist, but one does in a liquid crystal. The interactions between liquid crystals and light, electric and magnetic fields, X-rays, diffusing species, and the like, are dependent on the angle between the impressed forces and the director.

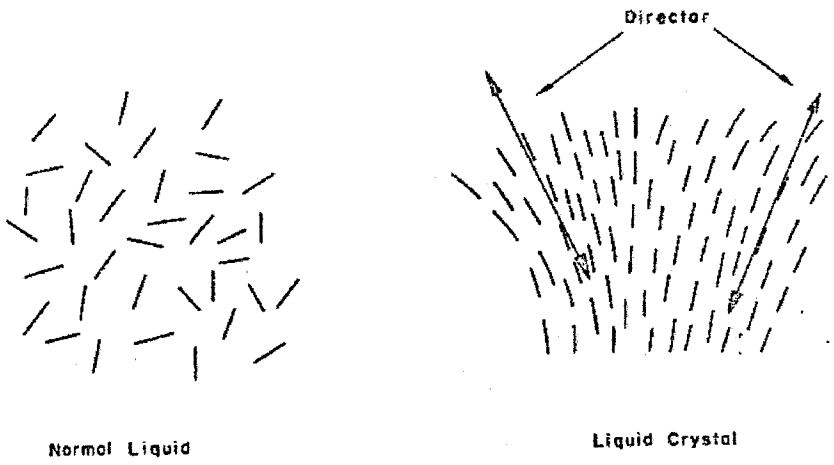


Figure A1. Normal Liquid and Liquid Crystal

Response to an applied field

Both normal liquids and molecules in a liquid crystals respond to applied magnetic and electric fields. Electric field induced molecular alignment (5-30%) in normal liquids (Kerr effect) results from the couple exerted on permanent and induced dipoles by the applied field in the presence of thermal agitation. In liquid crystals, the effect is two orders of magnitude greater because all the molecules move together. Because of this, a field of 10^6 V/m induces virtually 100% alignment.

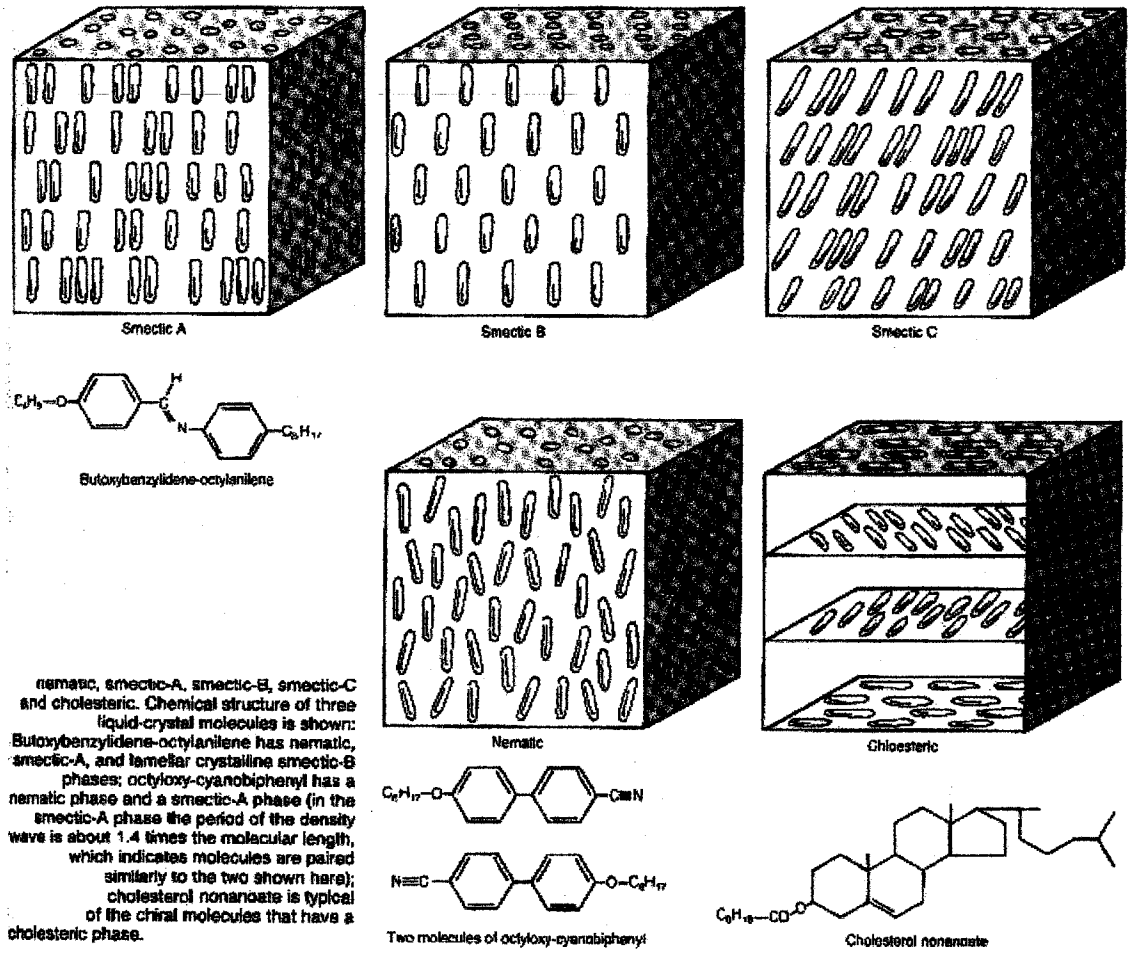
Large liquid crystal displays can be fabricated

By anchoring the molecular orientation at the surfaces of a thin crystal layer it is possible to create a single crystal with a thickness up to about a hundred microns. Only the molecular alignment is unique, the positions of the centers of the molecules change with time.

Liquid Crystal Types

The primary types of liquid crystals are shown in figure A2. They are as follows:

Nematic. Positional order is completely absent but the rod like molecules try to lie parallel to one another. Only molecules that are separated by several tens of micrometers show any significant departure from parallel alignment. Some Schiff bases, esters, and biphenyls exhibits a nematic liquid crystalline phase.



nematic, smectic-A, smectic-B, smectic-C and cholesteric. Chemical structure of three liquid-crystal molecules is shown: Butoxybenzylidene-octylanilene has nematic, smectic-A, and lamellar crystalline smectic-B phases; octyloxy-cyanobiphenyl has a nematic phase and a smectic-A phase (in the smectic-A phase the period of the density wave is about 1.4 times the molecular length, which indicates molecules are paired similarly to the two shown here); cholesterol nonanoate is typical of the chiral molecules that have a cholesteric phase.

Figure A2. Types of Liquid Crystals [3]

Smectic. There are several smectic types all of which exhibit the same tendency for molecular parallelism in all 3 dimensions. Smectics have a layered structure due to the tendency for the molecular centers to lie in well-defined planes. The director may or may not be normal to these planes and the centers may be random within the planes or may have varying degrees of order. Smectics, have high viscosity, and are sometimes used for memory additives for nematic crystals. By the way, smectic liquid crystals were originally used as alignment agents in detergents, due to their anisotropy.

Cholesteric. This liquid crystalline state occurs when the molecules are planar rather than rod-like. Thus, the molecules may stack parallel within one plane but may lie at a well defined angle to one another along' the normal to that plane. The structure is much like a nematic that has been twisted about the normal to the director. The pitch of the helical structure is a function of temperature, molecular type, and they often exhibit "chromatic" effects due to their layered pitch.

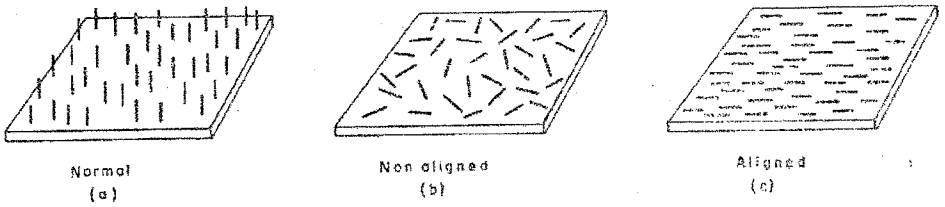
Optical Properties

The most obvious consequence of anisotropy is the highly refractive and sometimes turbid optical effects of liquid crystals in bulk form. The angle between the director and the light beam varies spatially and with the passage of time. As a result, the light is steered by the

refractive index variations and there is strong scattering away from the incident direction although very little light is backscattered. In nematics, the material is locally uniaxial, and the optical axis is parallel to the director. As expected, there are the usual birefringent or doubly refractive properties. In cholesterics, the symmetry axis is the helical axis so that optic axis and director are normal to one another. In addition to birefringence there are optical rotary effects.

Alignment and patterns

In the case of a thin (10-100 μm) liquid crystal layer contained between two ITO coated glass plates, surface treatment (coating with PVA or polyimide and rubbing unidirectionally) of these plates can lead to a stable well defined director orientation throughout the layer. Figure A3 shows orientation of the liquid crystal molecules perpendicular or parallel to the plane of the container walls. Cholesteric liquid crystals can only sustain a unique orientation when the director is in the plane of the glass surfaces. Then, the helical (optic) axis is normal to the surfaces and there are considerable optical effects along this axis. The structure, called ***Grandjean***, is unique, it being impossible to achieve any other arrangement by surface control[2]. Cholesterics frequently take up a structure in which short helical sections are packed in a more complicated, strongly scattering state which, although not fully stable can survive for long periods.



Zero field states of cholesterics and nematics.

Figure A3. Orientation of liquid crystal molecules at the substrate: (a) homeotropic or normal; (b) non-aligned; and (c) homogeneous or parallel alignment.

Response to electric fields

When the liquid crystal resistivity is very high (> than 10^{12} ohm-cm) and only dielectric response is involved, the applied field acts on both permanent and induced dipoles. The molecules have axial symmetry so that when the polarizability is greater parallel to the axis than perpendicular to it, the molecules align parallel to the field in order to minimize the energy as shown in Figure A4. For materials with greater polarizability across the

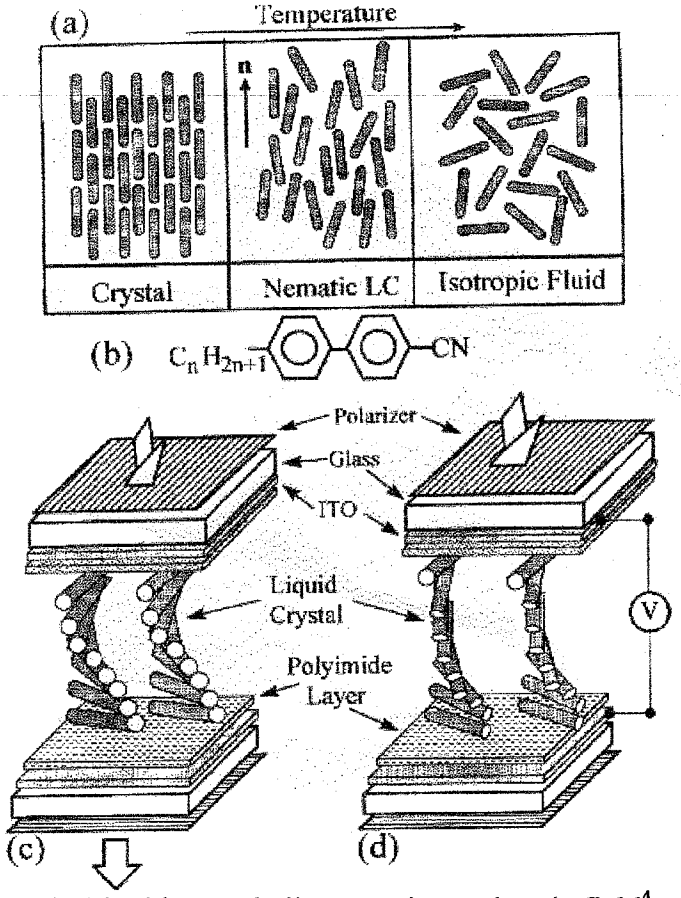


Figure A4. Liquid crystal alignment in an electric field[4]

molecular axis, the director aligns perpendicular to the applied field. The difference between the polarizabilities is expressed in the dielectric anisotropy ($\varepsilon_{//} - \varepsilon_{\perp}$), being positive when the parallel component is greater. The anisotropy usually seen in data sheets is for low frequencies and it should be remembered that it may diminish or change sign at frequencies above 5-10 kHz.

The addition of significant charge transport leads to a more complicated response. Figure A5 illustrates the response of a nematic liquid crystal, with relatively low resistivity, ($<10^{12}$ ohm-cm) and significant negative low frequency dielectric anisotropy. In zero field, surface control is used to set the director at right angles to the surfaces (parallel to the applied field). At a few volts, an applied field acts on the dielectric anisotropy and over most of the film, the director aligns perpendicular to the applied field. This situation is shown in Figure A5. As the applied field is increased, significant current is passed. Any distortion of the director, such as may be caused by thermal or vibrational effects, leads to a sideways displacement of charge due to the conductivity anisotropy. As indicated, this provokes an increase in the distortion and the situation is unstable, leading to a cellular, forced convection in the liquid. The same phenomenon may take place in a cholesteric liquid crystal with negative dielectric anisotropy. If the anisotropy is very small and the director is initially arranged to be parallel to the field, cellular convection may not occur. On the other hand, if the material has very weak positive

anisotropy and the director is initially arranged perpendicular to the applied field, cellular convection may occur.

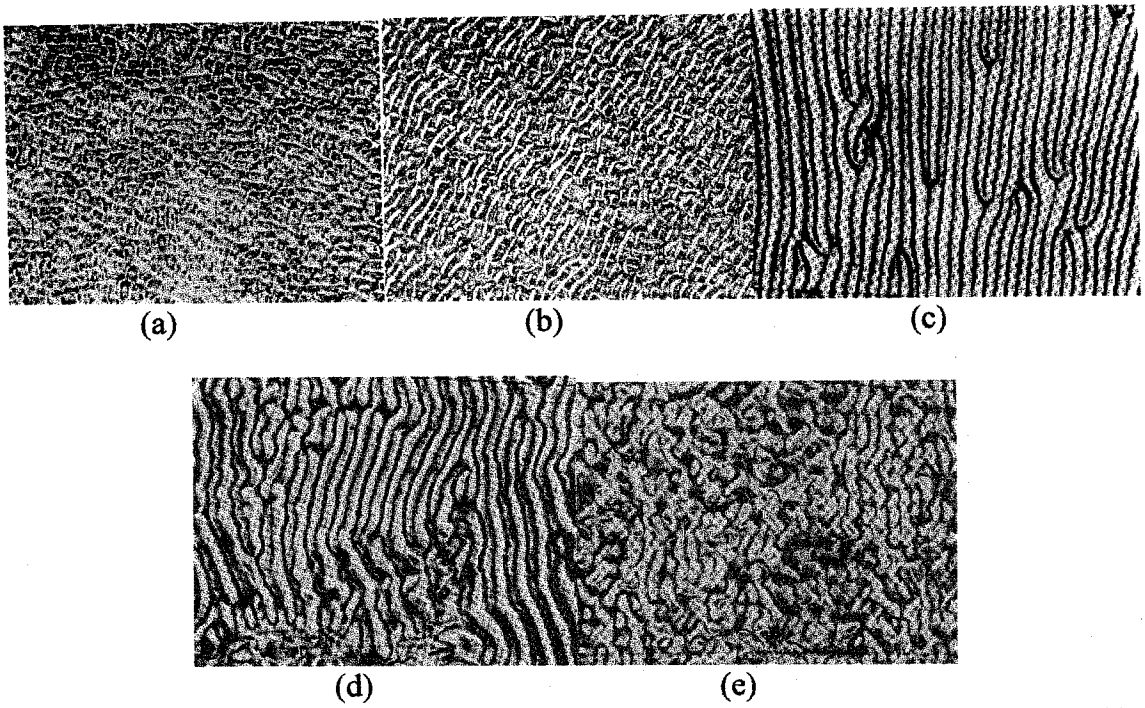


Figure A5. Patterns for dynamic scattering L.C. with voltages (a) 0V, (b) 1 V, (c) 2 V, (d) 3 V, and (e) turbulence above 4 V (RMS)

Device Fabrication

To make a crude electro-optic device, two glass plates, coated with a transparent conductor are spaced by a 25 micrometer thick Mylar spacer which is in two parts (Figure 3). After suitable surface treatment the plates are clamped to the spacer and are sealed together with epoxy resin all round the perimeter of the spacer except for two small areas corresponding to gaps in the spacer. The clamps are taken off when the epoxy has hardened and the cell is filled in vacuum by capillary action. A drop of liquid crystal is placed near one filling hole and the cell is placed on a tilting table in an enclosure which is rough pumped. After a suitable interval, the table is tipped, the liquid crystal fills the cell and air is let into the enclosure. Finally, the filling holes are sealed, care being taken to avoid contaminating the liquid crystal. This technique allows one to use very small quantities of material.

Electro-Optic Effects

(a) Dynamic Scattering

A nematic liquid crystal material, with low resistivity and negative dielectric anisotropy, will in general exhibit dynamic scattering. It is usual to treat the cell surfaces with lecithin or a similar surfactant to make the director normal to the cell surfaces. An applied steady voltage of about 2V/25 μm swings the director round until it lies in a plane normal to the field. This phenomenon, sometimes called the Frederiks Effect, is independent of frequency up to 50 kHz or above (see Figure A6). Further increase in a steady or low frequency (~ 50 Hz) applied voltage

leads to the convection, and, if this is driven beyond the streamlined flow condition, turbulence occurs. This disrupts all structure in the nematic film, causing strong light scattering ('dynamic scattering') which ceases when the current is reduced to zero. As shown in Figure A6, the dynamic scattering threshold voltage rises rapidly at the dielectric relaxation frequency which is inversely proportional to resistivity and dielectric constant. At low frequencies, the space charge inhomogeneity which results from the conductivity anisotropy, reverses its sense in sympathy with the applied field. The force exerted on the space charge is therefore unchanged as the applied field oscillates but only as long as the space charge distribution can reverse accordingly. Above the dielectric relaxation frequency, the alternating field acts on some mean charge displacement that causes the director to oscillate about its mean position. This causes scattering which is weak and has a threshold RMS voltage which increases as the square root of the frequency.

(b) Twisted Nematic Light Valve

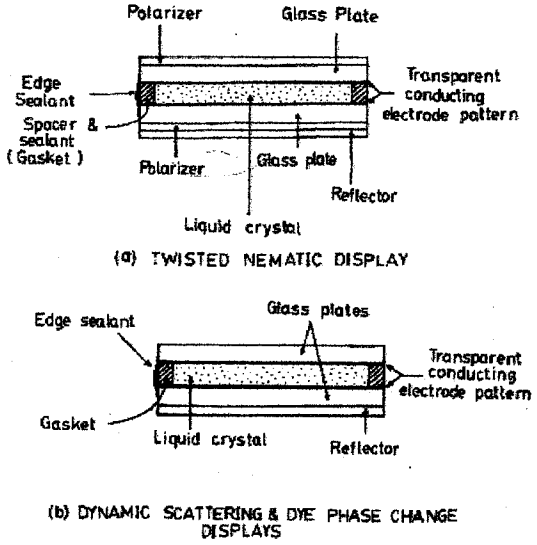


Figure A7. Construction of L.C. Valve for twisted nematic and dynamic scattering

Again a nematic liquid crystal is used, but resistivity, dielectric anisotropy and surface preparation are all different. The resistivity is made as high as possible by material purification, and the anisotropy is chosen to be positive. The surfaces are treated so that the director lies in the plane of the surface and along a well defined direction. However, this direction on one surface is arranged at right angles to the special direction on the other surface. The result is a twisted nematic structure that has the effect of rotating the plane of plane polarized light through 90°. A sandwich of the cell between two crossed polarizers leads to transmission whereas a cell between parallel polarizers leads to virtually no transmission (see Figures A4 and A7). When a small voltage (2V) is applied, the director rotates until the optic axis lies along the incident light direction. The 90° twist is lost and the transmitting sandwich becomes opaque (or the opaque sandwich transmits). The original effect is regained when the field is switched off.

(c) Cholesteric to Nematic Phase Change.

A cholesteric with positive dielectric anisotropy and high resistivity is used. The cholesteric is originally set in the clear stable structure with the optic axis normal to the cell

surfaces. An applied field aligns the molecules parallel to the field and parallel to one another. The result is that the material is no longer cholesteric but is nematic although the film remains clear. On removing the applied field, the cholesteric phase grows randomly throughout the film and the result is a disordered structure that scatters light and persists for some time. The working material can be made from a mixture of a normal cholesteric (usually having low anisotropy) and a high positive anisotropy nematic.

(d) Cholesteric Memory Effect.

This effect which involves a negative anisotropy cholesteric with low resistivity can be understood from a study of Figure A6 for dynamic scattering. The memory effect is in fact simply dynamic scattering, but in a cholesteric, the scattering state reverts only very slowly to the clear original structure. The optic axis is arranged perpendicular to the cell plates and so the film starts off clear. Application of a low frequency voltage leads to disruption of the film into a scattering condition which can persist for months after the current is stopped. Application of an alternating voltage above the Frederiks threshold and beyond the cut-off frequency causes a Frederiks effect which regains the original clear structure. The device thus has one stable and one metastable off state and thus exhibits memory.

References:

1. T. Kountotsis, "Liquid Crystal Display Design", Western New England College Summer Design Project, June, 1998 (present address General Dynamics, Pittsfield, MA) and B. Wilson, "Design of Color Liquid Crystal Display System", Western New England College Senior Design Project, June 1986 (present address AOX Corp, Dallas, TX).
2. J. Kirton., "Electro-Optic Effects In Liquid Crystals", Proc. Conf. Liquid Crystals, Kent State Univ., 1982. pp.46-57.
3. J. Litster and R. Birgeneau, Physics Today, Vol. 35, No.5, 1982. pp. 26-33.
4. G. P. Crawford, SAMPE Jnl., 32, 4 1996. pp. 22-28

DOOR RADIUS VS OPENING FORCE OR FREE-BODIES VS FISH-SCALES

Edward L. Widener

School of Technology
Mechanical Engineering Technology
Purdue University
1417 Knoy Hall, Room 145
West Lafayette, Indiana 47907-1317

Telephone: 765-494-7521
e-mail elwidener@tech.purdue.edu

Biography:

Prof. Widener has taught at Purdue University since 1978, concentrating on mechanics, materials, recycling, and communicating. Ed was in Malaysia from April 1995 - June 1996, teaching Metals Lab for new technology teachers. Memberships include ASEE, ASM, ASME, ISA, TAPPI. A registered P.E. in New York & Indiana, he was ABET accreditation visitor, from 1983-1990; and NSF lab-grants reviewer in 1989 and 1990. Between 1994-1977, he had night classes in Indianapolis, IN (IUPUI) and Danville, IL (Jr. College). Degrees from Purdue are BS '49 (physics) and BS '51 (ME); MSEM 62 (Hydraulics) is from University of Kansas. Between 1952-1978, Ed was a process or project engineer for Continental Group, Baker-McHenry-Welch, Kimberly-Clark. E.I.DuPont, Union Carbide, & U.S. Steel. In WW II, he was U.S. Navy S1/c aboard light-cruisers Vicksburg & Astoria.

Edward L. Widener

DOOR RADIUS vs OPENING FORCE
or Free-Bodies vs Fish-Scales

by Edward L. Widener, PE
Purdue University, MET Department
W. Lafayette, IN.

Key Words: Force, friction, gravity, inertia, moment, weight

Prerequisite Knowledge: Force=mass x acceleration; Weight=mass x gravity acceleration; Friction=coefficient of friction x normal force; Potential energy=weight x height; Kinetic energy=(1/2) (mass)(velocity squared).

Objective: To promote open-ended problem solving. To compare analytical solution (via free-body diagram) with experimental solution (via fish-spring scale).

Equipment & Materials:

1) Fisherman's Spring Scale (Sports Dept., Wal-Mart, 28-lb capacity, $3.00).
   Read to nearest quarter pound (4-oz avoirdupois).
2) Loop of String (cord or twine).
   Fasten scale hook to door handle.
3) Screw Driver (if needed).
   Disconnect door-closer piston.

Abstract:

New doorframes in commercial 6'hallways often are 5'x7', with 3'x7' and 2'x7' doors, mounted side-by-side. Often the 3'door has an automatic opener, for wheelchairs or cart clearance. Routinely we may use that 2'manual door to save energy. We assume the pull on our light-weight door (with 2'moment arm) is LESS than on the heavier door (with 3'moment). Your assignment (if you choose to accept it) is to PROVE IT. Analytically, a free-body diagram (3D) involves astute assumptions of door-construction and hinge-friction. But experimentally, a simple reading of a spring-scale showed our 3'door needed about 10% more pull than the 2'door.

Procedure:

Pulling forces can be rapidly and repeatedly read from a fisherman's spring-scale, hooked into a door handle. Some latches may require a loop of string to hook into. Does the pulling angle vary with wall-clearance? Does a fast pull take more force? Does a slow pull show less fluctuation? Does a panic-bar affect the pusher force (for oncoming traffic)?

Our scale is read to the nearest ¼ lb (4-oz); it also reads kilograms (force) to a tenth. And there is a built-in 3'steel ruler (1-metre long), read to 1/32 inch or 1-mm.

Other methods may involve a thin rubber strip (say 1/4''wide x 3'long), which is cut from an inner-tube (in bicycle or truck tire). Holding a ruler aside the strip and reading elongation is generally a 2-man job, assuming elastic behavior.

Other elastic bands involve white sewing-tape, with tan latex or white spandex fiber. Typically a ¼'' or ½'' width (1' or 2' long) provides adequate stretch. Using a thin, long,

rubber "tie-down" is an option, if clearance is no problem). Count floor-tiles (12" or 9" squares) to estimate distances and moment arms.

See FIG.I (3-D Free Body Diagram)

Results:

This plain scale consistently registered a 9-lb pull for the 3'door (versus 8-lb for 2'door) with slow motion. Disconnecting the door-closer or opener levers had no evident effect. Once moving, each door was easier to pull (about 1-lb less). Of course, increasing the door-speed or pull-angle did increase the pull force, say another pound. However, our spring then fluctuated and accuracy suffered; purchasing a better scale (about $30) is recommended.

Conclusions:

Using the 2'door does indeed save effort (say 10%) as well as electric power (avoid automatic opener) and equipment maintenance (levers and switches). Clearly the installed cost is lower (7 % less door area; no automatic opener). But lateral clearance is less (33%). Safety is enhanced (no sudden automatic swing).

We should compare costs of two standard automatic 3'doors, versus 3'/2'combination. In a 6' hallway, this is "Value Engineering".

For global equivalence, convert to S.I. metric architectures.

References:

1) Jacobs, J.A., & Kilduff, T.F., "Engineering Materials Technology", 4th ed., Prentice-Hall, Columbus OH, c.2001.
2) Parker, S.B. (Ed.), "McGraw-Hill Dictionary of Scientific & Technical Terms", 5th ed., NYCity, c.1994.
3) Hibbeler, R.C., "Engineering Mechanics: Statics & Dynamics", 7th ed., Prentice-Hall, Englewood Cliffs NJ, c.1995.

STRUCTURE AND MECHANICAL PROPERTIES OF THERMOPLASTIC COMPOSITES

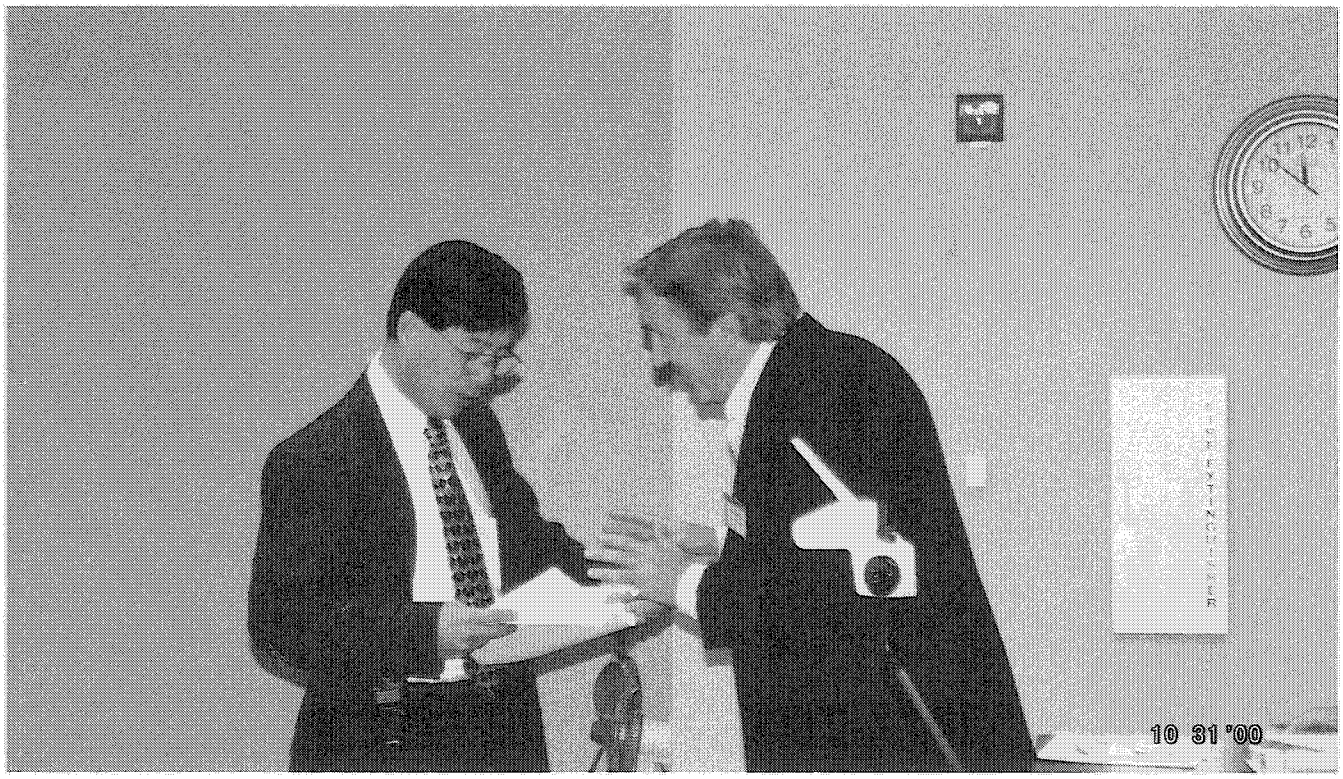
W. Richard Chung

Department of Chemical and Materials Engineering
San Jose State University
San Jose, California 95192-0082

Telephone: 408-924-3927
e-mail wrchung@email.sjsu.edu

Biography:

Prof. W. Richard Chung joined the faculty of San Jose State University in 1987. His primary teaching responsibility is in the Department of Chemical and Materials Engineering. He holds a Bachelor's degree in Chemical Engineering, a Master's degree in Materials Engíneering, and a Ph.D. in Mechanical Engineering. He has six years of industrial experience in three fields: paper and pulp, plastics manufacturing, and nuclear power plant design and construction. He also worked as a consultant for IBM, HP, Intel, and Lockheed Martin. His research interests include failure analysis of materials, smart composites, and failure behavior of plastics encapsulated microchips.



Structure and Mechanical Properties of Thermoplastic Composites

W. Richard Chung, Department of Chemical and Materials Engineering, San Jose State University, San Jose, California 95192-0082

Abstract:

In recent years there has been an immense interest in the fiber-reinforced thermoplastic composites. The main reasons for the interest are associated with the potential improvements in manufacturability, recyclability, reformability, composite properties, and work environment. The main attractions of using a thermoplastic matrix rather than a thermosetting one are related to the ease of manufacturing and the strengths achieved in a short time with no chemical reaction during the solidification process. In this study, glass and graphite fibers will be used to reinforce various thermoplastic matrices such as polyethylene, polypropylene and acrylonitrile-butadiene-styrene (ABS). Material parameters such as stacking sequence, reinforcement orientation, and fiber volume fraction will be varied in order to study their overall influence in mechanical properties. A set of control samples using the same types of fibers and thermosetting polyester will also be manufactured. A simple cost-effective compression molding technique will be used to manufacture the aforementioned composite laminates. Custom-made composite laminates will be machined into coupons that will be subjected to in tensile, impact, and flexural tests. The ASTM standard testing procedures will be carefully followed. Comparisons of mechanical properties between thermoplastic and thermosetting composites will be addressed. Emphasis will be placed on the relationship between structure and properties relative to material performance. The test results and failure mechanisms will be discussed and presented to the workshop.

Key Words: polyethylene, polypropylene, ABS, thermoplastic composite, thermosetting composite, consolidation, tensile test, impact test, and flexural test.

Prerequisite Knowledge: Basic knowledge of the difference between thermosetting and thermoplastic polymer matrix materials relative to manufacturing methods and mechanical behaviors.

Objectives: To understand the structure and mechanical properties of fiber-reinforced thermoplastic composites, and how their mechanical properties compare to those of thermoset composites.

Equipment and Materials:

1. A lamination press with temperature and pressure controls.
2. Metal molds for manufacturing composite square rods and panels.
3. Various types of thermoplastic resins (ABS, PE, PP), and a thermosetting (polyester) resin.
4. A bucket of cold water for cooling the specimens.

Safety Precautions:

1. Safety glasses and leather shoes must be worn when working in the laboratory.

2. Many chemicals, solvents, and catalysts can cause severe burns or irritation to skin and eyes. For this reason, every effort should be made to avoid contact with them. To prevent skin injuries, wear a pair of gloves, an apron, a shop coat, or even an old shirt or jacket.

3. Dust masks must be worn at all times when working on sanding, fine polishing, or machining of lab projects; these operations produce hazardous debris. Respirators must be worn when working with chemical fumes such as polyester, ABS, etc.

4. Thermal gloves must be worn during the process of transferring the heated metal molds to the water bath.

Introduction:

Continuous fiber-reinforced thermoplastic composites have emerged as a fast-growing area of the composite industry. Their excellent mechanical properties enable them to penetrate the traditional markets of wood, metals, and thermosetting polymers/composites. The growth rate for continuous fiber-reinforced thermoplastic composites has been 30% per year from 1990 to 1999. [Ref.1] The major benefit of switching from these traditional materials to the thermoplastic composites is to improve fracture toughness, shear strength, and to reduce manufacturing cost. [Ref. 4-7] The high market demand for thermoplastic composites is primarily driven by automotive applications. These include integrated front ends, load floors, truck beds, instrument panels, and integrated door panels. Based on a market overview released by the Society of Plastics Engineers, similar large part application development is occurring in recreation vehicles such as all terrain vehicles (ATV's), golf carts, snowmobiles; packaging applications such as pellets and containers; building and construction such as fencing, lumber replacement, etc. [Ref. 1&3] Melt impregnation using thermoplastic pultrusion is the dominant manufacturing technique used for continuous fiber-reinforced thermoplastic materials. However, other alternative manufacturing methods are also widely used: solution impregnation, powder impregnation, and extrusion impregnation. The powder impregnation method is the most economical in the manufacture thermoplastic composites.

Experimental:

In this experiment, commercially available glass and graphite fibers are used to reinforce thermoplastics such as polyethylene, polypropylene, and ABS. Melt impregnation via thermoplastic powder impregnation is employed to help manufacture custom made samples. For the purpose of comparison, a set of control samples using glass, graphite fibers, and thermosetting polyester resin are also produced. Two types of sample geometry are used: laminate panels and square rods. Material parameters such as stacking sequence, reinforcement orientation, and fiber volume fraction will be incorporated in order to study their influence in the overall mechanical properties. In this case, fiber orientations used are as 0, 45, and 90 degrees. A stacking sequence 0/45/90 is used throughout.

Unidirectional glass and graphite fabrics (1.5-mm and 1.7-mm thick, respectively) are cut to size (203.2 mm x 203.2 mm) and laid in a custom designed aluminum mold (Figure 2).

Thermoplastic resins in a powder from, ranging from 9 to 20μms, are uniformly dispersed onto the glass or graphite fabrics. A laminate with twenty-four layers $[+45/-45/0/90/-45/+45]_{2s}$, approximately 3-mm thick, was produced. The fiber volume fraction in the laminates was about 55-60%. The general manufacturing procedure for thermoplastic composites is to heat up the fabrics with the embedded resin powders above the melting temperatures (125°C for PE, 175°C for PP and 240°C for ABS), and then apply a relatively very low pressure. For PE and PP matrices, the ultimate operating temperature is higher than their melting temperatures, so as to eliminate all spherulite nuclei and then to re-solidify a more uniform crystalline structure. The laminate is then transferred to a laminating press that is held at a temperature slightly below the melting temperature (Figure 1). The pressure is approximately 4 MPa, and is applied for 30 minutes to ensure good consolidation. In this consolidation process the pressure brings the plies into intimate contact, and removes any entrapped air bubbles or voids. This pressure application time permits adequate resin flow and ensures strong interlaminar adhesion. Any reduction in pressure and/or pressure-application time that doesn't comprising laminate quality will enhance production cost and production rate. The mold is finally placed in a cold water bath such that the desired shape is maintained. After cooling to room temperature the mold is opened, the formed part is removed, and secondary operations such as a trimming and machining are performed.

Tensile and three-point bending specimens are cut from the laminates: impact bars are machined from the square rods. A "V" notch is cut into each of the impact specimens. Tests are performed in accordance with ASTM standards [D790 (bending test), D638 (tensile test), and D-256 (Izod impact test)]. Loading of tensile and bending specimens is relatively low such that deflection is below a maximum of 10 mm/min. Fractured samples are then examined using optical and scanning electron microscopy.

Results:

Test results are shown in Tables 1 and 2. Table 1 presents the mechanical properties for fiber-reinforced thermoplastic and thermosetting composites, whereas Table 2 contains properties for the graphite-reinforced materials. As noted in these tables, thermosetting composites (both glass- and graphite-reinforced) have higher tensile strengths. However, their impact and flexural strengths are generally lower than their thermoplastic counterparts. Among the thermoplastic composites, those with the ABS matrix exhibit the best mechanical properties. The fracture mechanism for impact damage from high-speed loading involves fiber breakage, matrix cracking, and delamination. On the other hand, a slow loading rate such as is found in tensile and flexural tests produces composite fracture behavior that is determined by the interfacial bonding strength and strain energy in the composite. Figure 3 and 4 (optical photomicrographs) show that the fracture process is often initiated from a large crack site; this is followed by crack propagation through the fiber-matrix interface. Studies using scanning electron microscopy, the results of which are shown in Figures 5 and 6, indicate that the poor interfacial bonding develops in the interlaminar area.

Conclusions:

Experimental data suggest no significant difference in unidirectional tensile properties between thermoplastic and thermoset composites. With different fiber orientations, the tensile properties for thermosetting composites are superior to thermoplastic ones. This is

mainly due to fiber fracture process. In general, thermoplastic composites offer better impact properties. Thermosetting composites offer strong tensile and flexural strengths.

Recommendations:

Further research work in the determination of fiber wetting condition and interfacial boding strengths of thermoplastic composites will be desirable. Projects can be extended to structure design, processing techniques, and environmental considerations (temperature, solvent, aging process).

References:

1. Bowen, Stephen T. Long Fiber Reinforced Thermoplastics (LFRTP) Market Overview, SPE Newsletter, Composite Division, Vol. XI, No.2, April 2000.

2. Carlsson, Lief A. (Editor), Thermoplastic Composite Materials, Vol.7, Elsevier Science Publishing: New York, New York, 1991.

3. Holty, David H., Greene, Tim L., Muzzy, John D., and Parkin, Michael J. Performance Advantages of Thermoplastic Composite Tubes in Sports Applications, SME Composites in Manufacturing, Vol.12, No.1, First Quarter 1996.

4. Kausch, Hans-henning (editor), Advanced Thermoplastic Composites: Characterization and Processing, Hanser Publishers: Munich, Germany, 1993.

5. Newaz, Golam M. (editor), Advances in Thermoplastic matrix Composite Materials, STP 1044, ASTM: Philadelphia, Pensylvania, 1989.

6. Rasato, Dominick V., Designing with Reinforced Composites, Hanser/Gardner Publications: Cincinnati, Ohio, 1997.

7. Swanson, Stephen R., Introduction to Design and Analysis with Advanced Composite Materials, Prentice-Hall: Upper Saddle River, New Jersey, 1997.

Table 1. Mechanical Properties of Glass Fiber-Reinforced Thermoplastic and Thermosetting Composites

Types of Composites	Tensile Stress (MPa)	Strain to Failure (%)	Notched Izod Impact Strength (J/m)	Flexural Strength (MPa)
0/90 Glass/PE	63	2.7	65	86
±45/0/90/±45 Glass/PE	65	2.8	60	89
0/90 Glass/PP	95	2.4	93	112
±45/0/90/±45 Glass/PP	100	2.2	95	120
0/90 Glass/ABS	101	2.4	109	125
±45/0/90/±45 Glass/ABS	113	2.1	113	129
0/90 Glass/Polyester	85	1.1	77	206
±45/0/90/±45 Glass/Polyester	90	0.9	75	210

Table 2. Mechanical Properties of Graphite Fiber-Reinforced Thermoplastic and Thermosetting Composites

Types of Composites	Tensile Stress (MPa)	Strain to Failure (%)	Notched Izod Impact Strength (J/m)	Flexural Strength (MPa)
0/90 Graphite/PE	75	1.7	66	56
±45/0/90/±45 Graphite/PE	76	1.5	70	69
0/90 Graphite/PP	93	1.1	80	88
±45/0/90/±45 Graphite/PP	97	0.9	82	89
0/90 Graphite/ABS	112	1.3	88	119
±45/0/90/±45 Graphite/ABS	118	1.5	85	121
0/90 Graphite /Polyester	570	0.6	59	335
±45/0/90/±45 Graphite/Polyester	695	0.4	54	366

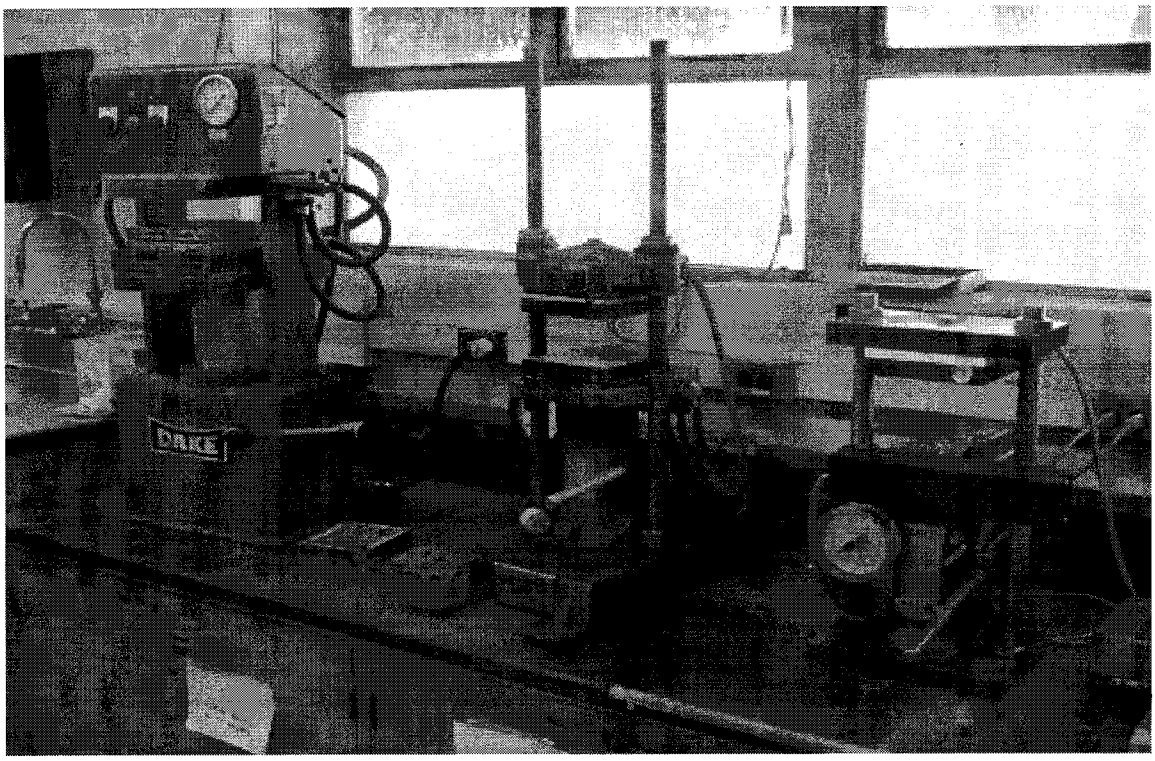


Figure 1. Lamination Presses in the Composite Laboratory.

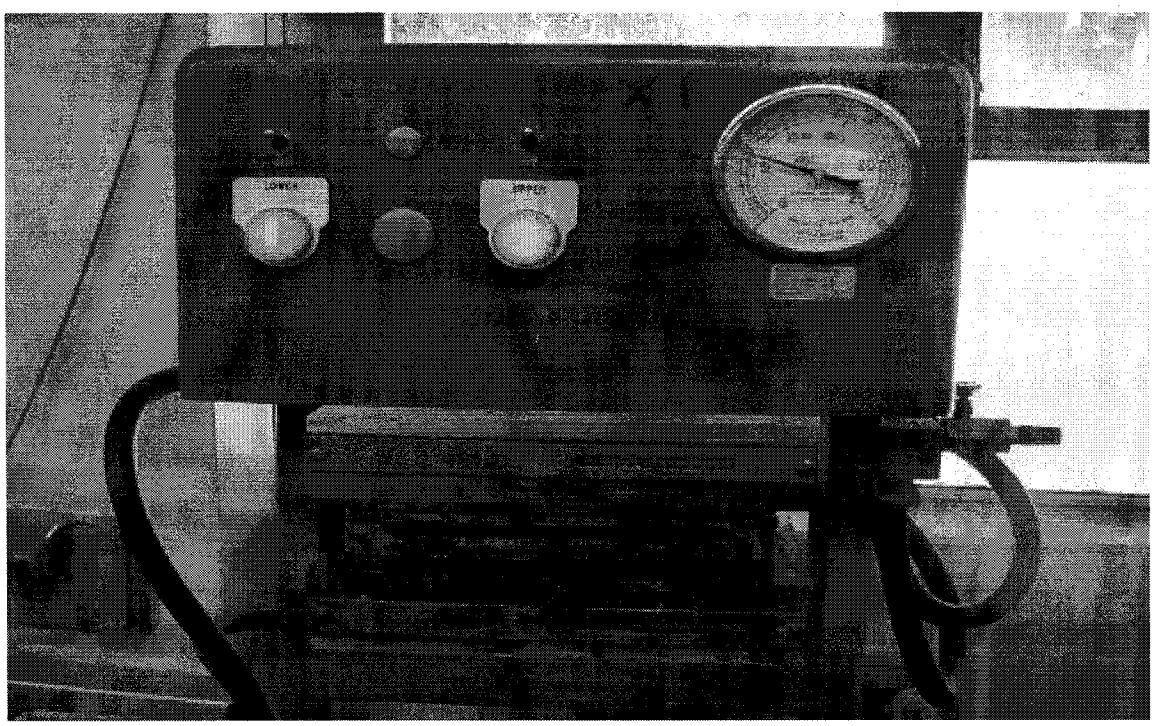


Figure 2. An Aluminum Mold Is Being Placed between Two Heated Platens with Pressure.

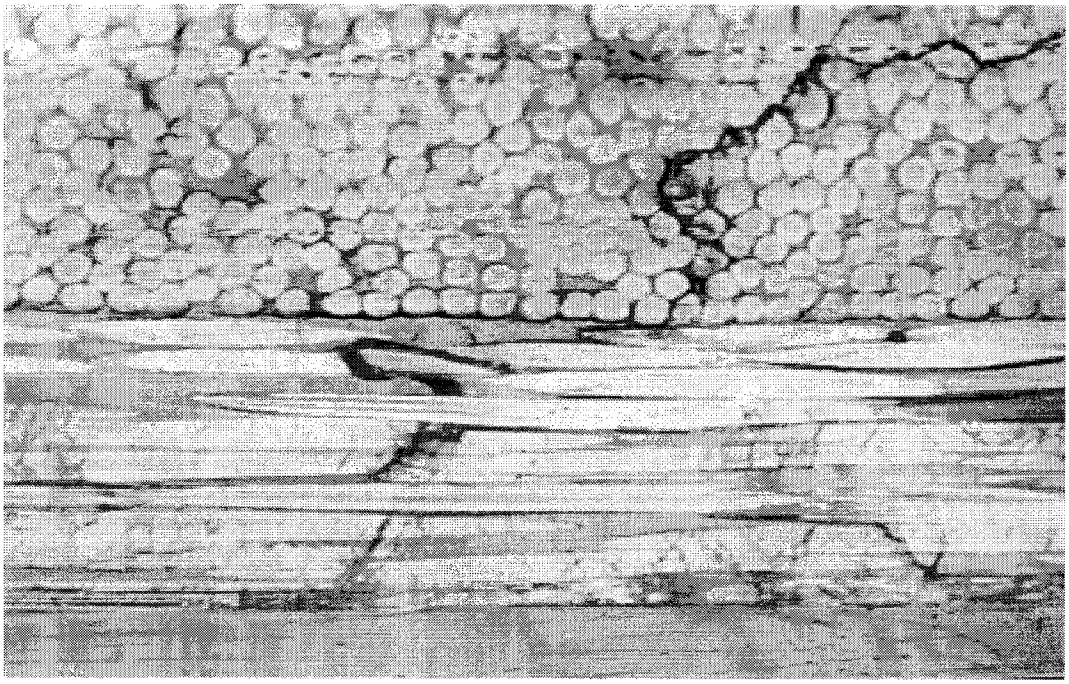


Figure 3. Cracks Initiated at Lower Right Corner; Interlaminar Fiber Debonding.

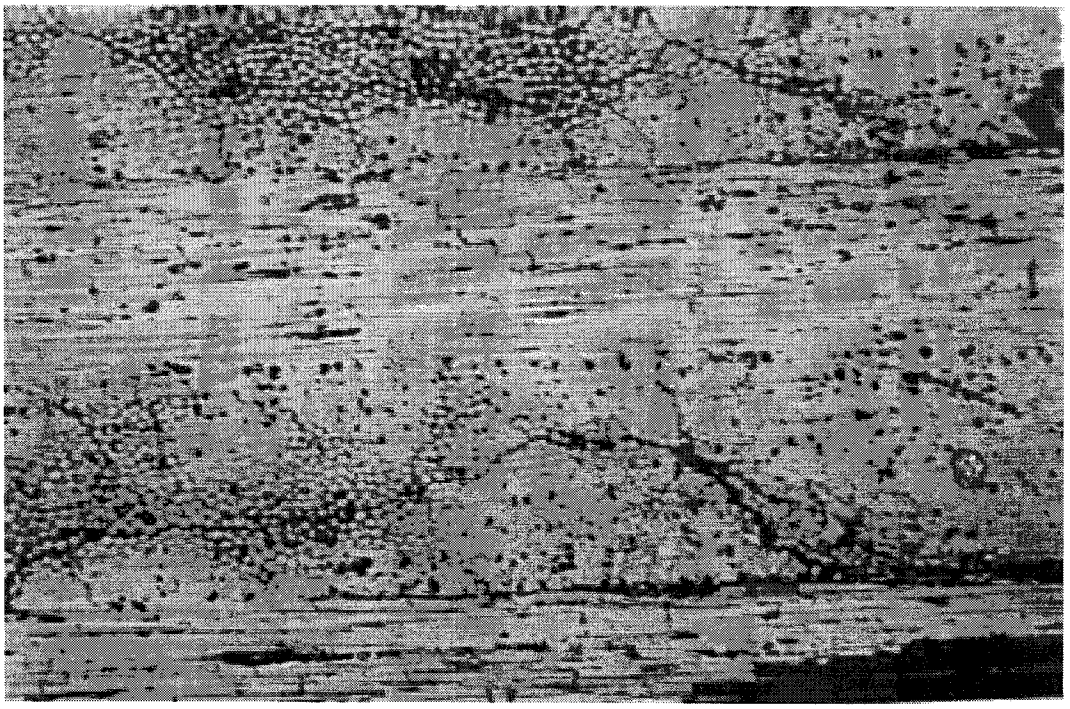


Figure 4. Fracture Cracks Propagated through 0 and 90-Degree Fiber Orientations

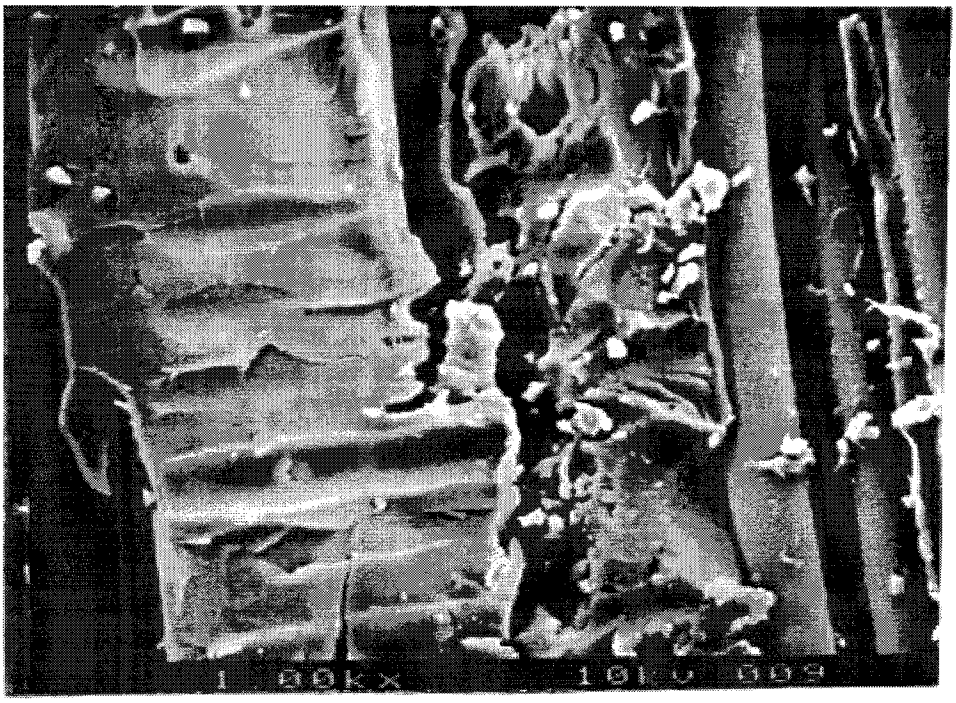


Figure 5. Fracture in Thermoplastic Matrix with Extensive Delamination.

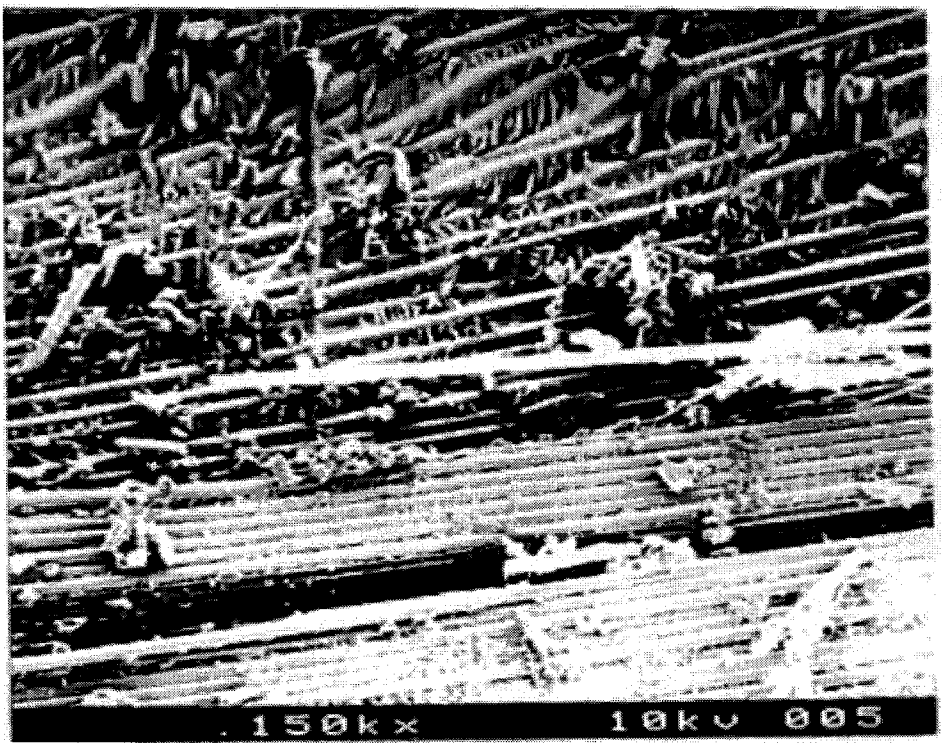


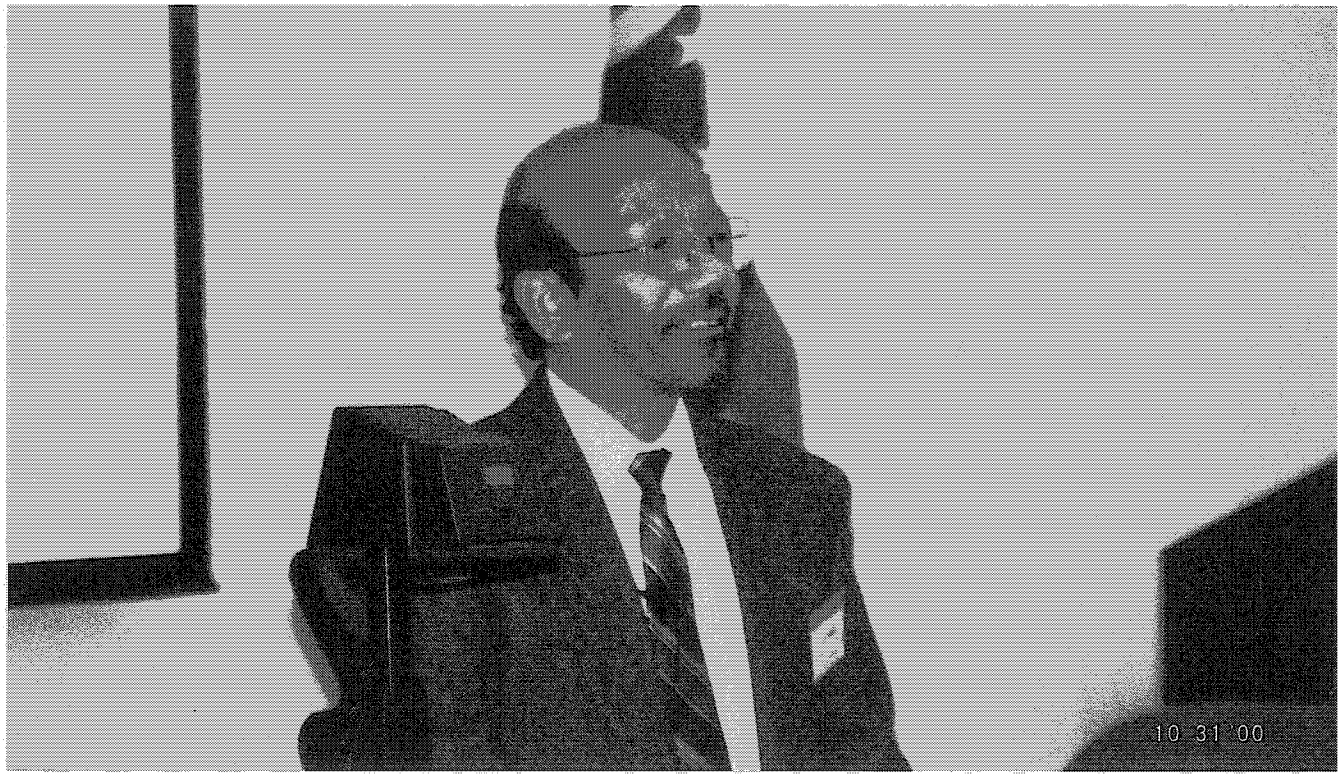
Figure 6. Poor Interfacial Bonding and Fiber Breakage Shown in Thermoplastic Composites.

LIGHTWEIGHT AUTOMOTIVE MATERIALS DATABASE

P. K. Mallick

Department of Mechanical Engineering
University of Michigan-Dearborn
Dearborn, Michigan 48128

Telephone 313-593-5119
e-mail pkm@umich.edu



P. K. Mallick

Lightweight Automotive Materials Database

Prof. P. K. Mallick
University of Michigan-Dearborn
Dearborn, MI 48128

Lightweight Automotive Materials (LAM) Database

- Independent and neutral source of information on leading-edge lightweight automotive materials
  - Metals
  - Polymers
  - Composites
  - Ceramics

Database Contents

- Encyclopedic information on automotive materials
  - Properties
  - Processing information
  - Test methods
  - Application examples

Database Contents

- Archival information on important findings from literature (abstracts from journals and conferences) on automotive materials
  - Structure and properties
  - Processing technologies
  - Design methods
  - Application examples

Novel Features

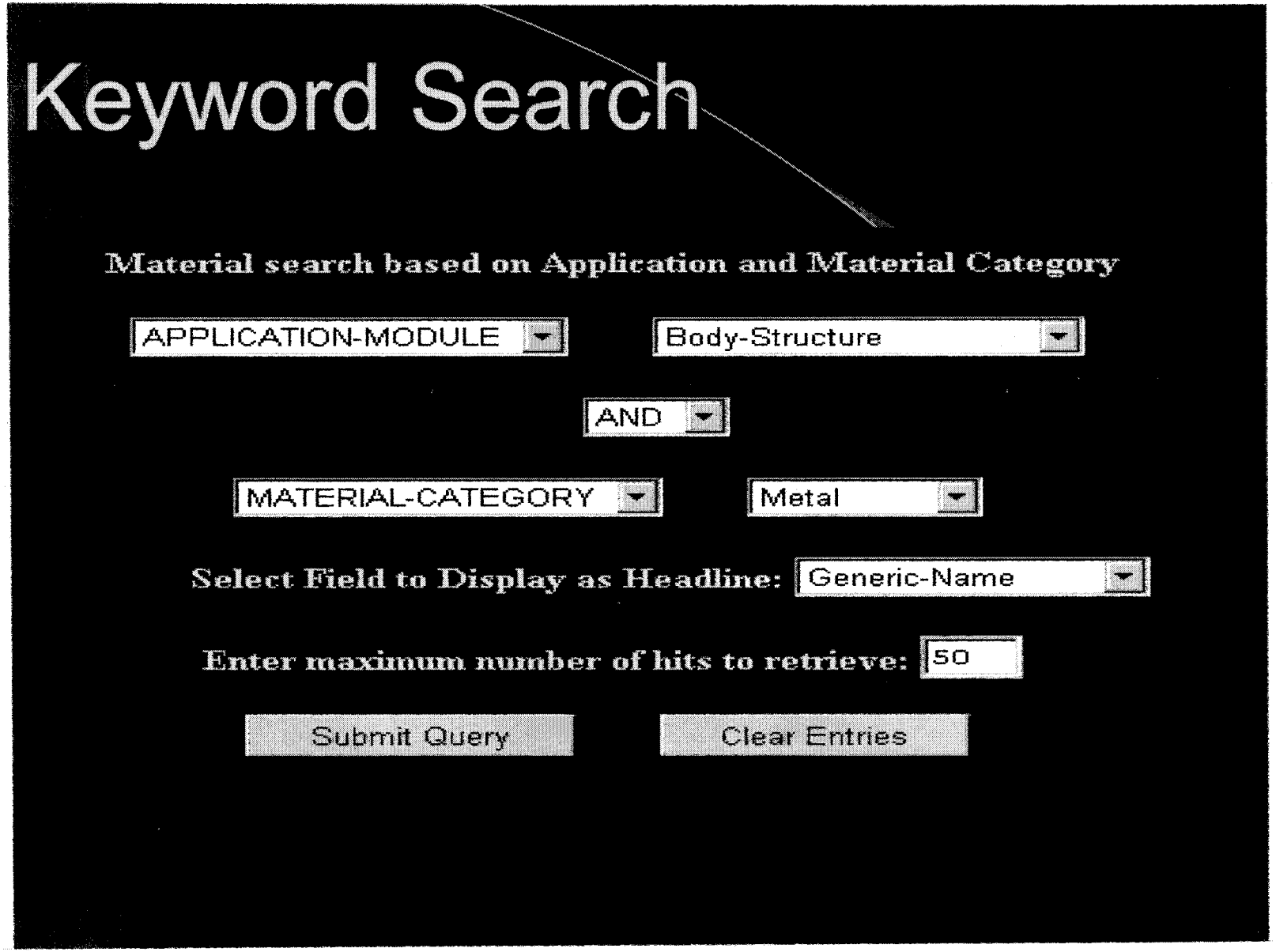
- Sophisticated searching facilities
  - Boolean searches (exact match on keywords)
    - e.g. - Find all metals that are used in the manufacturing of body parts
- Material-specific property chart
- Material search based on key properties

Novel Features

- User-friendly browsing facility
  - By application modules (e.g. - Engine)
  - By material categories (e.g. - Composites)
  - By material names (e.g. – Aluminum Alloy 6009)
  - By associative links / references
- Internet access via the web
  - Web based searching and browsing

Application Modules

- Body structure
- Body panels
- Instrument panel
- Seats
- Bumpers
- Doors
- Lighting
- Electrical & electronic
- Brake
- Suspension
- Springs
- Frame
- Transmission
- Drive shaft
- Under-the-hood
- Engine
- Steering
- Wheel


Keyword Search
Material search based on Application and Material Category
APPLICATION-MODULE
Body-Structure
AND
MATERIAL-CATEGORY
Metal
Select Field to Display as Headline:
Generic-Name
Enter maximum number of hits to retrieve:
50
Submit Query
Clear Entries

Lightweight Automotive Materials Database

Matching Record: 4

Match Number: 1 of 4
Headline Field : Generic Name: Aluminum Alloy-6009
Click to view document: [*Full*]

Match Number: 2 of 4
Headline Field : Generic Name: Aluminum Alloy-6061
Click to view document: [*Full*]

EnterProperty	-	-	
EnterProperty	-	-	
			Fatigue Properties
Fatigue Strength	MPa	115	
Cyclic Yield Strength	MPa	-	
K'	MPa	-	
n'	-	-	
Fatigue Strength Coefficient	MPa	82.8(85.2)	
Fatigue Strength Exponent (b)	-	-0.0983(-0.0957)	
Fatigue Ductility Coefficient	-	0.924(0.561)	
Fatigue Ductility Exponent (c)	-	-0.794(-0.746)	
			Electrical Properties
Electrical Conductivity	MS/m	26	
Electrical Resistivity	Ohm-m	39×10^{-6}	
			Processing Properties

FRACTURE BEHAVIOR OF NYLON MONOFILAMENT FISHING LINE

Wayne L. Elban

Loyola College
Department of Electrical Engineering and
Engineering Science
4501 North Charles Street
Baltimore, Maryland 21210

Telephone: 410-617-2853
e-mail welban@loyola.edu

Biography:

Since 1985, Professor Elban has taught engineering science courses at Loyola College, including introductory materials science, materials science lab, mechanical properties of materials, and transformations in solids. He received a BChE with distinction ('69) and a PhD in Applied Sciences: Metallurgy ('77) from the University of Delaware and a MS in Engineering Materials ('72) from the University of Maryland, College Park. From 1969-1985, he was a research engineer at the Naval Surface Warfare Center, White Oak Laboratory, Silver Spring, Maryland. He is a member of ASM International.

Wayne L. Elban

FRACTURE BEHAVIOR OF NYLON MONOFILAMENT FISHING LINE

Wayne L. Elban
Dept. of Electrical Engineering and Engineering Science
Loyola College
Baltimore, Maryland 21210

ABSTRACT: A procedure is described for characterizing the fracture behavior of commercial 6-lb test nylon monofilament fishing line. A bench-top universal testing machine is used to obtain determinations of tensile fracture load (strength) and displacement (elongation at break). Emphasis is given to placing specimens in several fixture configurations to distinguish valid experimental data from that influenced by testing artifacts. Specimens with a single overhand knot are tested to determine its stress concentrating effect. As-manufactured fishing line and exterior sample surfaces immediately behind the fracture surfaces are examined using a reflected light microscope. Experimental determinations of mechanical properties are compared to values appearing in the literature.

KEY WORDS: Uniaxial tensile testing, reflected light microscopy, mechanical deformation properties, fracture, stress concentration, manufacturing defects, thermoplastic polymers, nylon, monofilament fishing line.

PREREQUISITE KNOWLEDGE: sophomore-level undergraduate laboratory experiment requiring basic knowledge of thermoplastic polymers and their mechanical deformation/fracture behaviors and of mechanical property testing as described in an introductory materials science course and accompanying laboratory course.

OBJECTIVES:

(a) Experimental Goals:

1. to measure the uniaxial tensile mechanical properties to fracture of a commercial thermoplastic polymer;

2. to distinguish valid versus invalid experimental data;

3. to assess the effect of stress concentration in a thermoplastic polymer;

4. to identify possible manufacturing defects in a commercial thermoplastic polymer using reflected light microscopy; and

5. to assess the brittle-ductile character of fracture of a thermoplastic polymer.

(b) Learning Goals:

1. to become familiar with uniaxial tensile testing, a prominent technique for characterizing the mechanical response of materials;

2. to become familiar with the occurrence of testing artifacts and their effect on experimental data and their interpretation;

3. to become familiar with bulk-deformation processing (extrusion/drawing) and its effect on the mechanical properties of thermoplastic polymers;

4. to become familiar with the effect of stress concentration on material deformation/fracture behaviors;

5. to become familiar with reflected light microscopy, a prominent technique for assessing material microstructure, using various types of illumination; and

6. to become familiar with the distinctive features of brittle and ductile fracture.

EQUIPMENT AND MATERIALS: (1) Chatillon model LRX universal testing machine (bench top model with 500-lb capacity); (2) Wedge-action grips (Chatillon model TG15N); (3) Bollard wire, yarn, and thread grips (Chatillon model TG12N); (4) Metric universal dial caliper (Brown and Sharpe 559-579-13); (5) Ruler; (6) Zeiss model ICM 405 bench metallograph; (7) Extruded nylon monofilament fishing line [South Bend No. M-146 6-lb test (or equivalent)] (Instructor Note 1); (8) Extruded nylon monofilament fishing line [South Bend No. M-146 6-lb test (or equivalent)] attached to 1" x 1.5" cardboard tabs using hot glue gun (Instructor Note 2).

SAFETY PRECAUTIONS: Care must be taken to avoid being burned when using hot glue gun to attach fishing line to cardboard tabs. (Instructor Note 2)

INTRODUCTION:

Problem Statement: You have recently been hired as a materials engineer by a manufacturer of nylon (Table 13.1, Ref. [1]) monofilament fishing line. You are asked to investigate whether customer complaints of 6-lb test nylon monofilament line breaking at loads below the advertised test force are valid. Your company recently acquired a new universal testing machine (Chatillon model LRX) equipped with a couple of different types of grips. The tester is computer controlled and has computer data acquisition capabilities, and your boss wants you to use it with appropriate grips in your assessment of the maximum force and corresponding displacement (extension) of the fishing line in question. Further, your boss suspects that the real explanation for any low-force failures is the presence of knots in the line that are introduced by the customers or more likely by their children. (Instructor Note 3) Your boss also asks you to perform a microscopic examination to gain relevant microstructural information. There is an interest in determining whether surface flaws are

present in the as-manufactured fishing line and in assessing the character of the resultant fracture surfaces and their vicinities.

Nylon is a prominent example of a large class of industrially important materials known as thermoplastic polymers. Their structure is usually linear, although branching is possible. Nylon is synthesized by condensation reaction, and typical uses include outdoor fabrics, carpet fibers, and monofilament fishing lines (introduced by Berkley in 1957 [2]). Upon heating above room temperature, thermoplastic polymers undergo significant changes in their elevated temperature mechanical properties as determined, for example, by uniaxial tensile testing, including decreases in elastic (Young's) modulus and fracture strength and increase in elongation at break. However, chemical decomposition is minimal.

Taking advantage of the elevated temperature properties of thermoplastic polymers, filaments are manufactured by a continuous extrusion process [3-5]. The starting materials are pellets, granules, or powders of polymer already synthesized to the desired molecular weight. These are delivered into an extruder barrel containing a slightly undersized screw that blends and transports the starting material along the barrel. Frictional heating results, that can be supplemented by exterior heaters, causing the polymer to melt. A pressure build-up also occurs as the material progresses down the barrel. The molten polymer then travels through multiple cylindrical dies located at or beyond the far end of the barrel. The extrudate is typically water-cooled and collected onto rollers or spools. This material then passes through a series of rollers to draw or stretch the filaments.

From a materials science viewpoint, the essential characteristic of the drawn filament is its highly anisotropic structure and properties. The intense shearing action during the extrusion process causes some segments of the linear polymer molecules to begin aligning themselves in the flow field, particularly as they travel through a die. The drawing operation greatly improves the alignment of molecules along the filament longitudinal axis. As a result, the highest tensile strength is realized in this direction as desired, for example, in nylon monofilament fishing line. However, transverse strength is significantly lower.

The purpose of this experiment is to investigate the fracture behavior of nylon monofilament fishing line. To this end, a quantitative evaluation of fracture strength and elongation at break will be made from uniaxial tensile testing measurements. The usefulness of several different specimen fixtures will be assessed by noting where specimen failures occur. Line diameters will be measured before and after testing. Subsequently, representative resultant fracture surfaces and their immediate vicinities will be examined to determine their character (i.e., degree of brittle versus ductile fracture) using reflected light microscopy. As-received line and other regions of tested line will also be examined for manufacturing defects and evidence of slip and kink band formation, respectively. To verify determinations of strength and elongation, the experimental values will be compared with those values for nylon appearing in the literature.

PROCEDURE:

A. TENSILE TESTING (Instructor Note 4)

1. Measurements:

   a. Measure the diameter of each specimen using a dial caliper prior to tensile testing.

   b. Perform tensile testing (specimen gage length = 4 in. or 4¾ in. when using bollard grips; crosshead speed (CHS) = 1 in./min -- Instructor Note 5) on five (5) specimens minimum for the following sample types:

      (i) bare 6-lb test nylon monofilament line using wedge-action grips (Instructor Note 6);
      (ii) 6-lb test nylon monofilament line with cardboard tabs using wedge-action grips (Instructor Note 6);
      (iii) bare 6-lb test nylon monofilament line using bollard grips; and
      (iv) bare 6-lb test nylon monofilament line with single overhand knot (positioned roughly in middle) using bollard grips.

   For each specimen, note where failure occurred.

2. After testing, place transparent tape around both specimen pieces near gripped ends; tape keeps specimen pieces together and provides a convenient label for handwritten identification.

3. Retain all specimen pieces for subsequent dimension measurements and examination.

4. Record your measurements and any relevant observations in your laboratory notebook with one or more drawings as appropriate.

B. DIAMETER MEASUREMENTS OF RECOVERED SPECIMENS

1. Using a dial caliper, measure the diameter of each specimen no more than several millimeters away from the break.

2. Record your measurements and any relevant observations in your laboratory notebook with one or more drawings as appropriate.

C. MICROSCOPIC EXAMINATION OF RECOVERED SPECIMENS

1. Preparatory Reading Assignment:

   a. Read Restivo [6], providing information on the operation of reflected light microscopes and types of illumination.

b. Read Vander Voort [7], providing additional information on types of illumination.

2. Using the Zeiss model ICM 405 bench metallograph with brightfield illumination, examine a segment of untested (as-manufactured) fishing line for the presence of surface flaws.

   Begin by devising a technique to view the segment along the filament axis. Describe this technique with appropriate drawing in your laboratory notebook. (Instructor Note 7)

   Record any relevant observations of the surface in your laboratory notebook with one or more drawings as appropriate.

3. Examine a representative tensile specimen, both with and without a knot, tested with bollard grips.

   Record your observations of the fracture surface and neighboring regions along the line axis. Pay particular attention to the degree of roughness of the fracture surface and whether it is nominally perpendicular to the line axis. Since the transverse strength of the line is expected to be considerably below the longitudinal strength, axial splitting is also possible. Assess whether brittle or ductile failure [8] appears to have occurred. Determine whether the line has undergone a significant decrease in diameter (i.e., necking as shown in Figure 13.18, Ref. [9]) in the vicinity of the fracture surface. Also, determine whether there is any evidence for slip band or twin boundary formation (Figure 2.5, Ref. [10]) and look for porosity and microcracks.

4. For a representative specimen with and without a knot tested with bollard grips, obtain a low magnification (i.e., 50X) photomicrograph using Polaroid Type 57 film (3000 ASA/36 DIN) with each of the following illuminations [6,7] (Instructor Note 8):

   a. brightfield;
   b. darkfield;
   c. polarized light; and
   d. differential interference contrast (Nomarski).

5. Record any benefits and additional microstructural information gained using the latter three illuminations.

D. ANALYSIS

Perform the following analyses and respond to any questions as completely as possible, being sure to show all of your work and reasoning as partial credit can be earned.

1. Tensile testing measurements -- for each sample type, do the following:

   a. Tabulate the measured values of fracture force and displacement at break; and

   b. Calculate [11] the average and standard deviation, σ, for both sets of values.

2. Discuss what happens when bare fishing line is tested using wedge-action grips. Emphasis should be given to the validity of the data and explain what is physically happening to the specimens.

3. Discuss what happens when fishing line attached to cardboard tabs is tested using wedge-action grips. Emphasis should be given to the validity of the data and explain what is physically happening to the specimens.

4. Discuss what happens when bare fishing line is tested using bollard grips. Emphasis should be given to the validity of the data and explain what is physically happening to the specimens.

5. Discuss what happens when bare fishing line with a single knot is tested using bollard grips. Emphasis should be given to the validity of the data and explain what is physically happening to the specimens.

6. Conclude which is correct, the complaints of customers or the suspicion of your boss. Be sure to justify carefully your answer based on the measurements that you obtained.

7. For the line tested using the bollard grips:

   a. Calculate fracture strength (σ_f) and elongation at break (e_b) for each specimen using engineering stress-strain relationships (e.g., Eqns. (2-1) and (2-2), Ref. [12]):

$$\sigma_f = F_f/(\pi d_o^2/4), \qquad (1)$$

   where F_f = fracture force in force-displacement curve, lb_f, and
   d_o = initial diameter of specimen, in.; and

$$e_b = \Delta l_b/l_g, \qquad (2)$$

   where Δl_b = corresponding displacement at fracture (break) in force-displacement curve, in., and
   l_g = specimen gage length.

   b. Calculate [11] the average and standard deviation, σ, of these determinations (Instructor Note 9).

c. Compare calculated values to literature values for nylon reported in Table 13.3, Ref. [13]. Discuss the reason(s) why agreement is poor if that is the case.

8. Specimen diameter measurements:

   a. Calculate the change in diameter, Δd, in units of mm, for each specimen using:

$$\Delta d = d_t - d_o, \qquad (3)$$

   where d_t = diameter of recovered specimen tested in tension, mm, and
   d_o = initial diameter of specimen, mm.

   b. Calculate [11] the average and standard deviation, σ, of this determination for each sample type.

9. Discuss the effect that tensile testing has on the dimensional stability of the specimens.

10. Discuss the evidence for as-manufactured surface flaws in the fishing line.

11. Discuss the character of the fracture surface for specimens with and without knots.

12. Discuss any microstructural features observed along the fishing line away from the fracture surfaces.

13. Discuss the benefits of using darkfield, polarized light, and differential interference contrast (Nomarski) illuminations.

COMMENTS with Data Sheets and Plots:

All of the experimental steps were performed a number of times to verify that the results are reproducible. The data sets appearing in this section are considered to be representative for the South Bend line. A complete set of measurements obtained for 6-lb test line from a different vendor (Berkley) appears in the Appendix. (Instructor Note 1)

Effect of Specimen Fixture on Uniaxial Tensile Testing Response: Force and displacement measurements taken from experimental curves (e.g., Figure 1) are given in Table I for the South Bend fishing line placed in various fixtures. The average breaking force of the bare line tested in the wedge-action grips is 3.00 lb_f (13.3 N), which is 50.0% of the line's advertised lb-test rating. However, the results obtained with this fixture are invalid because fracture occurred at one of the grips rather than in the specimen middle as desired. The fracture location indicates that the grip has a stress concentrating effect on the line causing premature failure at an artificially low force.

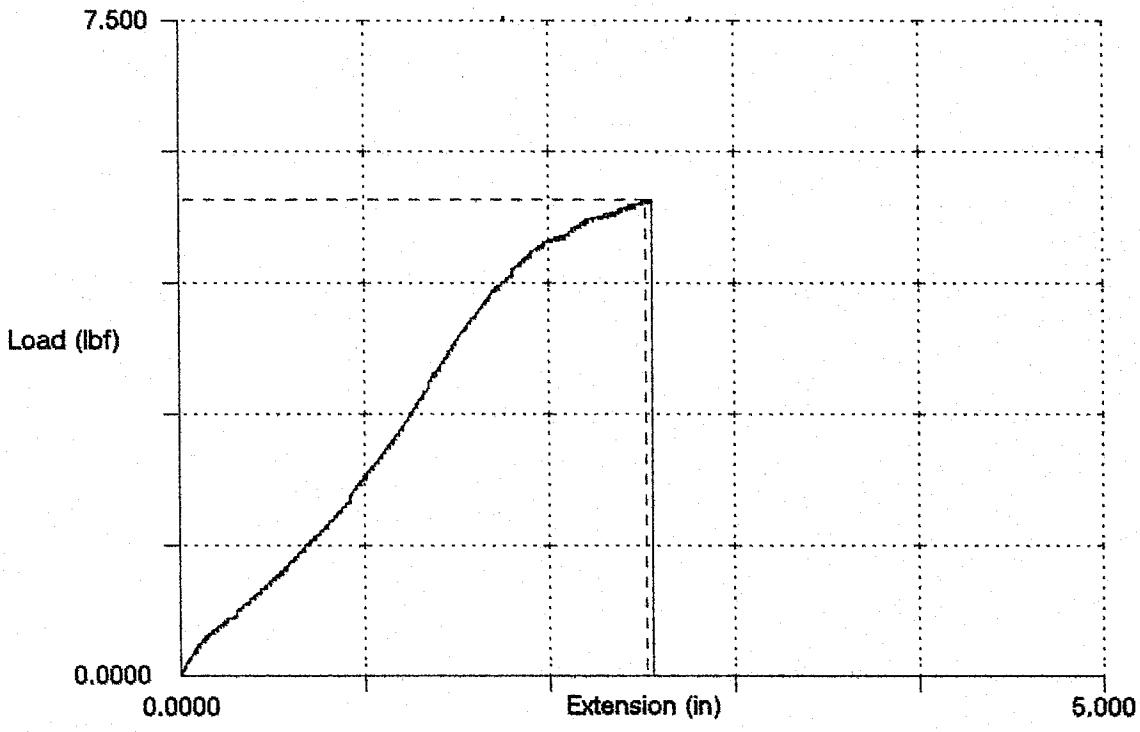


Figure 1. Force-displacement curve for South Bend six-pound test nylon monofilament fishing line (specimen SB1400) tested with bollard grips in uniaxial tension.

Table I. Force and Displacement Measurements for South Bend Six-Pound Test Nylon Monofilament Fishing Line

Specimen Fixture		Specimen Designation	Fracture Force* (lb_f)	Displacement at Break* (in.)	Comments
Wedge-action grips		SB0100	3.418	0.7269	Fractured at bottom grip
		SB0200	2.950	0.4952	Fractured at top grip
		SB0300	2.828	0.5249	Fractured at top grip
		SB0400	3.133	0.5748	Fractured at top grip
		SB0500	3.072	0.6726	Fractured at top grip
		SB0600	2.584	0.4780	Fractured at top grip
	Avg.:		**3.00 [13.3 N]**	**0.579**	
	σ:		**0.28 [1.3 N]**	**0.10**	
Wedge-action grips with cardboard tabs		SB0700	3.418**	0.7056**	Pull out at bottom tab
		SB0800	4.272**	0.9012**	Pull out at top tab
		SB0900	4.679**	0.9568**	Pull out at bottom tab
		SB1000	3.072**	0.6872**	Pull out at top tab
		SB1100	5.045**	1.253**	Top tab twisted in grip before pull out
		SB1200	4.801**	1.027**	Pull out at bottom tab
	Avg.:		**4.22 [18.7 N]**	**0.922**	
	σ:		**0.80 [3.6 N]**	**0.21**	
Bollard grips		SB1300	5.371	2.567	Fractured in middle; kinked
		SB1400	5.452	2.520	Fractured near top bollard; less kinking
		SB1500	5.432	2.657	Fractured near bottom bollard; kinked
		SB1600	5.574	2.644	Fractured in middle; kinked
		SB1700	5.432	2.639	Fractured in middle; kinked
		SB1800	5.696	2.864	Fractured in middle; kinked
	Avg.:		**5.49 [24.4 N]**	**2.65**	
	σ:		**0.12 [0.53 N]**	**0.12**	

Table I. Force and Displacement Measurements for South Bend Six-Pound Test Nylon Monofilament Fishing Line, Cont'd.

Specimen Fixture	Specimen Designation	Fracture Force* (lb_f)	Displacement at Break* (in.)	Comments
Bollard grips with filament knot	SB1900	3.560	1.548	Fractured at knot
	SB2000	3.723	1.601	Fractured at knot
	SB2100	3.947	1.688	Fractured at knot
	SB2200	3.947	1.616	Fractured at knot; slightly kinked
	SB2300	3.398	1.474	Fractured at knot; slightly kinked
	SB2400	3.703	1.572	Fractured at knot
	Avg.:	**3.71 [16.5 N]**	**1.58**	
	σ:	**0.22 [0.96 N]**	**0.072**	

* Obtained from computer analysis of force-displacement curve.

** Maximum force reported rather than fracture force since filament pull out occurred rather than fracture; displacement at maximum force reported rather than at break for the same reason.

The average breaking force of line with cardboard tabs tested with wedge-action grips improved to 4.22 lb_f (18.7 N), corresponding to 70.3% of the line's rating. These results are also invalid because failure now occurs by filament pull-out, which is analogous to the interfacial failure that is sometimes observed in continuous fiber/polymer matrix composites [14]. The filament end is devoid of adhesive (hot glue), indicating that the filament/adhesive interfacial bond broke. Failure by filament pull-out results in a series of pronounced load drops in the tensile response (Figure 2). Maximum force (reported in this case, rather than fracture force which did not occur) is achieved immediately prior to commencement of pull-out. Successive extension is accompanied by additional pull-out events, each occurring at a force lower than that necessary for the initial event since the bonded area is decreasing.

Bare line tested in bollard grips yielded an average breaking force of 5.49 lb_f (24.4 N). Although this is the highest value obtained using the three specimen fixtures, it is still only 91.5% of the line's rating. The force-displacement curve (Figure 1) exhibits what appears to be a yield point a little prior to breaking that is believed associated with the observations of kinking in recovered specimens. Four of the six specimens broke in the middle, while fracture in the remaining two occurred near (but not at) a bollard. As such, the bollard that takes up the filament before it is clamped in each grip successfully isolates the specimen from the deleterious effect of clamping. Thus, all of these measurements are valid, and assertions by customers are credible.

Effect of Specimen Knot on Uniaxial Tensile Testing Response: Bare line with a single overhand knot tested in bollard grips yielded an average breaking force of 3.71 lb_f (16.5 N). This corresponds to attaining 67.6% of the breaking force for the same line without a knot and compares favorably with a number of values obtained [15] from analogous sets of measurements for different 30- and 50-lb test nylon monofilament lines. The tensile curve (Figure 3) failed to exhibit the apparent yield point seen in Figure 1, presumably because the breaking force was below that necessary to cause prominent kinking. As expected, all six specimens broke at the knot, demonstrating the notch weakening effect that occurs in nylon. The stress-concentration factor for the knot is relatively modest: estimated [16] to be about 1.3 initially and to decrease to 1.2 as the knot tightened to breaking. The combined results reveal that the boss' suspicion has a sound technical basis.

Literature Comparison: The resultant fracture strength and corresponding elongation determinations for bare South Bend fishing line tested in bollard grips appear in Table II. There is very poor agreement between the experimental strength of the oriented nylon monofilament fishing line and that appearing in the literature for bulk polymer; an average value of 78,400 psi (540 MPa) was obtained for the fracture strength versus a value of 11,800 psi (81.4 MPa) reported [13] for the tensile strength of commercial-grade material. However, there is very good agreement for the ductility parameter; an average value of 56% was obtained for the elongation at break compared with a reported [13] value of 60%. The relatively high fracture strength of the fishing line is attributed to the polymer molecules becoming aligned during the drawing operation along what is to become the tensile axis. As such, a relatively high percentage of strong intramolecular bonds oppose the applied force compared to relatively randomly oriented bulk polymer, where a much higher percentage of significantly weaker intermolecular bonds participate.

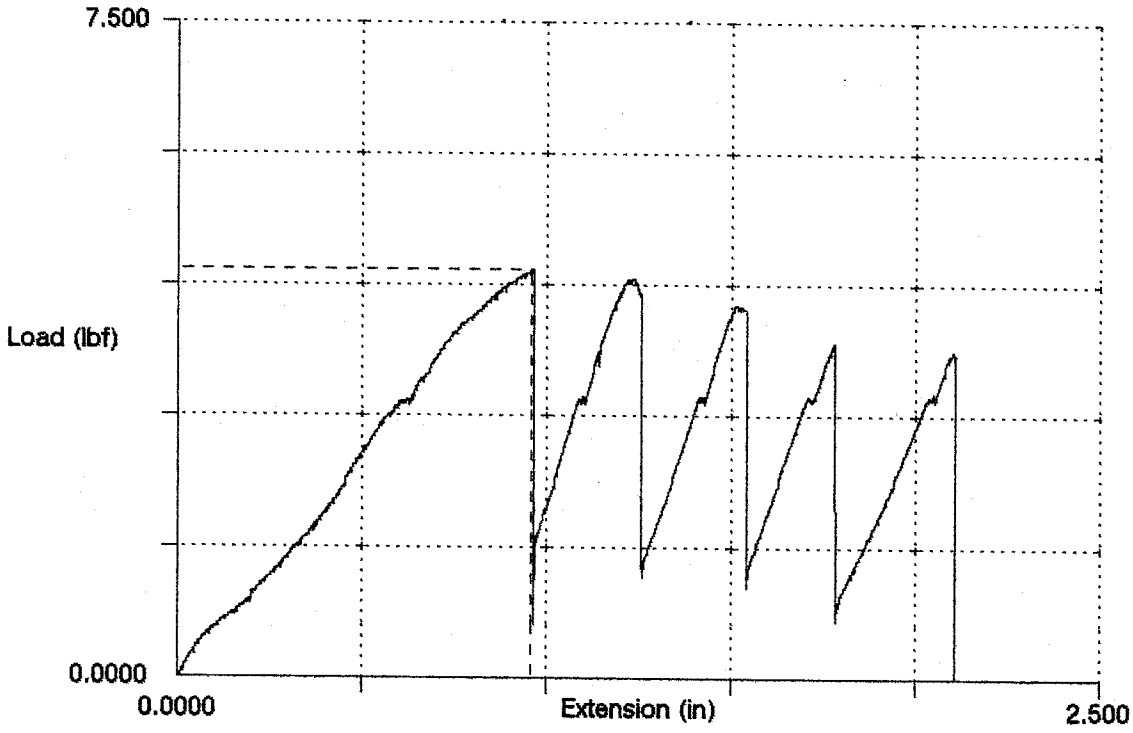


Figure 2. Force-displacement curve for South Bend six-pound test nylon monofilament fishing line with cardboard tabs (specimen SB0900) tested with wedge-action grips in uniaxial tension.

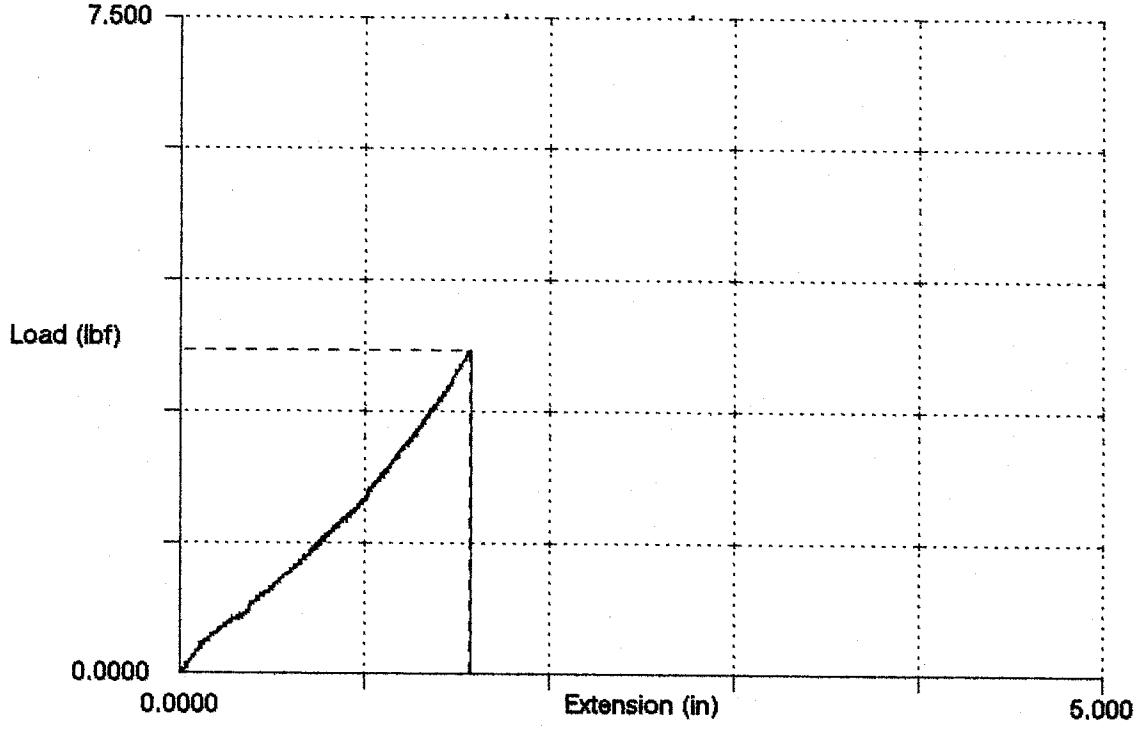


Figure 3. Force-displacement curve for South Bend six-pound test nylon monofilament fishing line with single overhand knot (specimen SB2400) tested with bollard grips in uniaxial tension.

Table II. Mechanical Property Results for South Bend Six-Pound Test Nylon Monofilament Fishing Line

Specimen Fixture	Specimen Designation		Fracture Strength (psi) [MPa]	Elongation at Break (%)
Bollard grips	SB1300		76,600 [528]	54
	SB1400		77,800 [536]	53
	SB1500		80,800 [557]	56
	SB1600		76,300 [526]	56
	SB1700		77,500 [534]	56
	SB1800		81,200 [560]	60
		Avg.:	**78,400 [540]**	**56**
		σ:	**2100 [15]**	**2**

Diameter Change Assessment: Diameter measurements obtained before and after testing each specimen appear in Table III. Changes in diameter are also provided. For a given sample type, no statistically significant change in diameter was measured, indicating that necking did not occur, unless extremely localized in the vicinity of the break.

Microscopic Observations: Fishing line specimens were examined with all four illuminations to assess their usefulness. Brightfield illumination yielded photographs with a great deal of undesirable scattered light, while darkfield illumination was impractical because so little light reached the objective lens making for extremely long exposure times. Both polarized light and differential interference contrast (Nomarski) provided excellent results, and several photomicrographs are referred to in the discussion that follows.

Examination of as-received line revealed (Figure 4) numerous small surface pits and several longitudinal scratches. The most prominent defects were a series of nearly equally spaced, shallow circumferential grooves that resemble small necked regions and probably formed during the drawing operation. Other portions of the line segment had frequent surface pits without additional grooves, indicating that the grooves are not present throughout. Nonetheless, these observations additionally support customer claims that the fishing line does not perform as rated since the defects would serve to initiate fractures resulting in reduced breaking forces.

The fracture surface (and immediate vicinity) of line tested with bollard grips revealed (Figure 5) that brittle tensile failure occurred in the absence of axial splitting. A high degree of roughness was present as the fracture surface was jagged and appeared to be torn. The irregular surface is attributed to the fracture path "seeking out" low molecular weight, low crystallinity regions that are interspersed unevenly among regions of high molecular weight and high crystallinity. [17] The low molecular weight, low crystallinity regions serve as "Griffith-like" flaws; brittle fracture results when the material experiences high enough stress to cause these flaws to grow. There was no apparent necking, but a short kinked region may be present. A separate kinked region about ¼ in. from the break had (Figure 6) two bright transverse bands near the center of the bent region and numerous fine transverse lines that may be more closely spaced in the bent region, all of which are attributed to slip and kink band formation [18].

The knotted region behind the fracture surface exhibited (Figure 7) significant ductility manifested as pronounced flattening of the line resulting from transverse (compressive) loading as the knot tightened during tensile testing. Examining the other fracture surface of this specimen revealed that brittle fracture also occurred, although compared to Figure 5, the degree of surface roughness was significantly less. Axial splitting did not occur for the knotted specimen either.

INSTRUCTOR NOTES:

1. This particular nylon monofilament fishing line is estimated to be about ten years old and has undergone degradation in mechanical properties that is typical of nylon line this old, such that the 6-lb test rating is no longer achieved. This line was chosen because this unexpected

Table III. Specimen Diameter Results for South Bend Six-Pound Test Nylon Monofilament Fishing Line

Specimen Fixture	Specimen Designation	Initial Diameter (mm)	Final Diameter (mm)	Change in Diameter (mm)
Wedge-action grips	SB0100	0.25	0.25	0.00
	SB0200	0.25	0.245	-0.005
	SB0300	0.245	0.24	-0.005
	SB0400	0.245	0.24	-0.005
	SB0500	0.245	0.245	0.00
	SB0600	0.24	0.24	0.00
			Avg.:	**-0.003**
			σ:	**0.003**
Wedge-action grips with cardboard tabs	SB0700	0.24	0.24	0.00
	SB0800	0.24	0.24	0.00
	SB0900	0.245	0.24	-0.005
	SB1000	0.245	0.245	0.00
	SB1100	0.24	0.235	-0.005
	SB1200	0.245	0.245	0.00
			Avg.:	**-0.002**
			σ:	**0.003**
Bollard grips	SB1300	0.24	0.235	-0.005
	SB1400	0.24	0.24	0.00
	SB1500	0.235	0.23	-0.005
	SB1600	0.245	0.24	-0.005
	SB1700	0.24	0.225	-0.015
	SB1800	0.24	0.24	0.00
			Avg.:	**-0.005**
			σ:	**0.005**

Table III. Specimen Diameter Results for South Bend Six-Pound Test Nylon Monofilament Fishing Line, Cont'd.

Specimen Fixture	Specimen Designation	Initial Diameter (mm)	Final Diameter (mm)	Change in Diameter (mm)
Bollard grips with filament knot	SB1900	0.245	0.24	-0.005
	SB2000	0.245	0.245	0.00
	SB2100	0.24	0.24	0.00
	SB2200	0.24	0.24	0.00
	SB2300	0.24	0.24	0.00
	SB2400	0.24	0.24	0.00
			Avg.:	**-0.001**
			***σ*:**	**0.002**
	Overall Avg.:	**0.243**		
	***σ*:**	**0.004**		

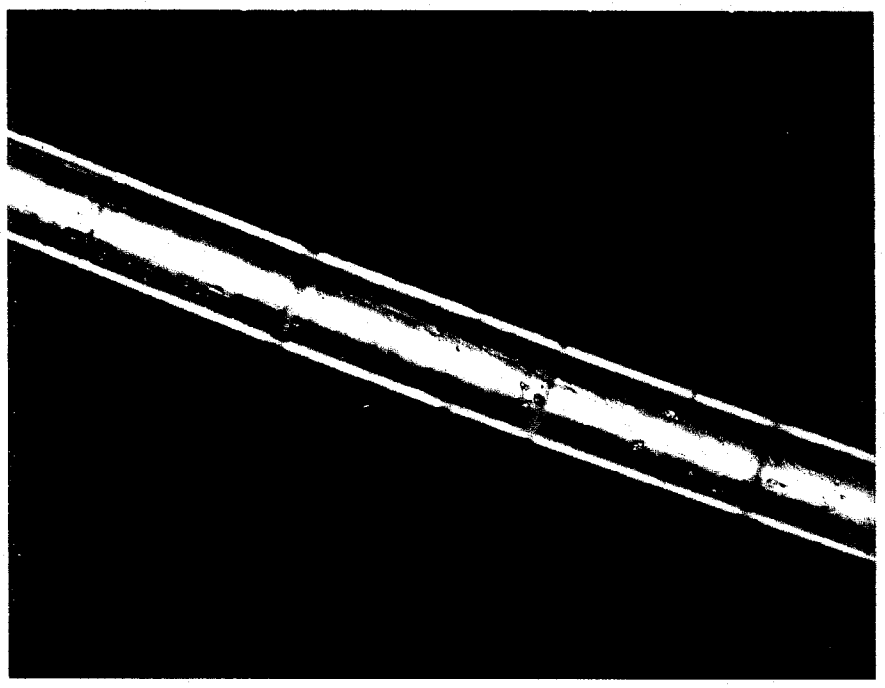


Figure 4. Photomicrograph (differential interference contrast: Nomarski) of exterior surface of as-manufactured South Bend six-pound test nylon monofilament fishing line.

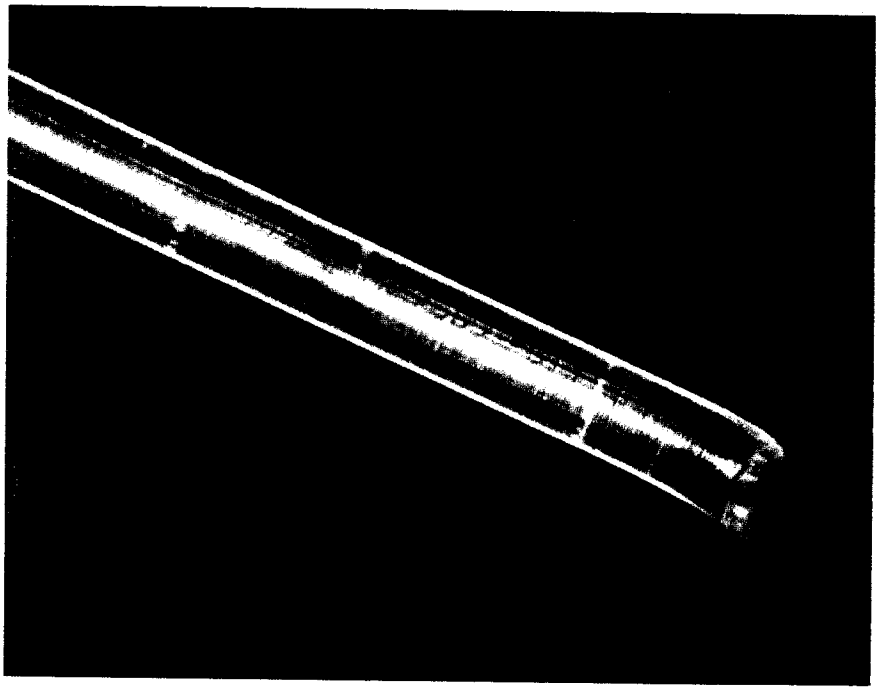


Figure 5. Photomicrograph (polarized light) of near-fracture surface region of South Bend six-pound test nylon monofilament fishing line tested with bollard grips (specimen SB1400).

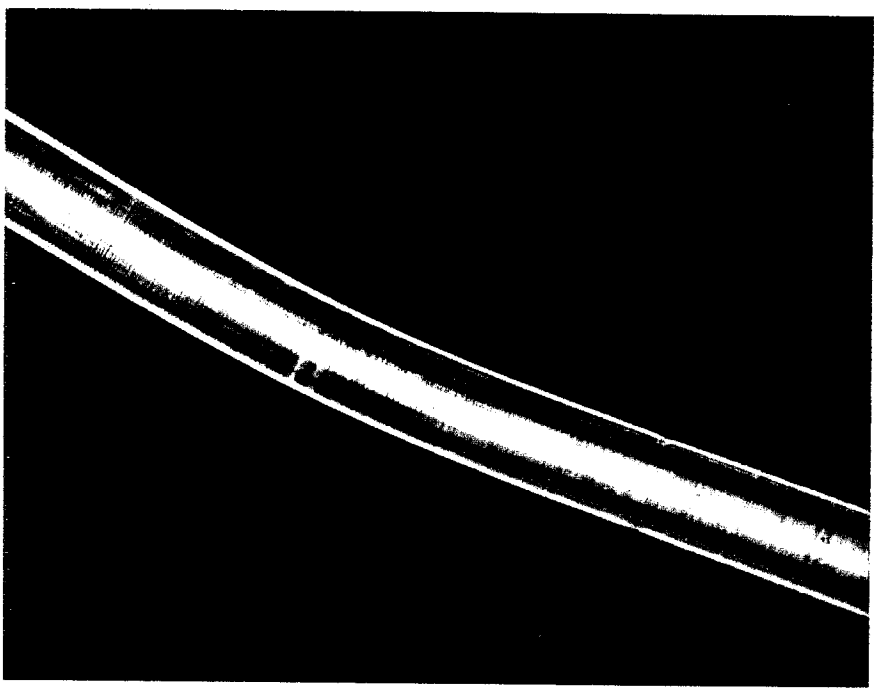


Figure 6. Photomicrograph (polarized light) of kinked region ~ ¼ in. from fracture surface of South Bend six-pound test nylon monofilament fishing line tested with bollard grips (specimen SB1400).

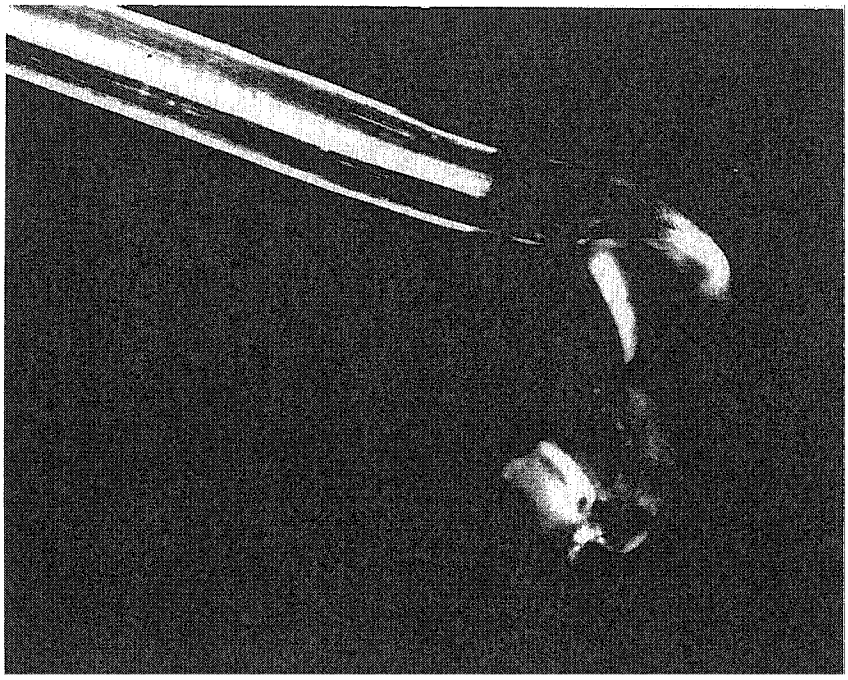


Figure 7. Photomicrograph (polarized light) of fracture surface region of South Bend six-pound test nylon monofilament fishing line with knot tested with bollard grips (specimen SB2400).

(for the student) complication allows the student to exercise critical thinking skills beyond having to sort out which specimen fixtures give invalid test data. A second set of test data/results for more recently manufactured line from a different vendor (Berkley) is included in the Appendix. This material still yields (actually exceeds) the stated (6-lb) test rating.

2. This specimen fixture must be created before actual testing. The procedure is done the day before to allow the glue to set up completely. Students can be given this task depending on their schedules. Preparatory to assembling specimens, 1" x 1.5" cardboard tabs are made using a paper cutter. The cardboard backing on paper pads provides excellent starting material. If students are involved, they should be shown how to operate a hot glue gun and to position line specimens onto tabs while being glued. See **SAFETY PRECAUTIONS.** Line is centered along the long dimension of one tab, and hot glue is applied directly to the line/tab. The second tab is quickly laid on top and firmly pressed down for about a minute until the glue gels. The procedure is repeated to create a second "sandwich" (line between two tabs). Once cool, excess line and glue can be easily trimmed with scissors.

3. This part of the experiment relates to a previous year's National Educators' Workshop paper [19] providing a very nice description for evaluating the load reducing (stress concentrating) effect of knots in various lines and threads.

4. Students should be shown how to operate the universal testing machine and to position specimens in the machine prior to actual testing. Consideration should be given to having students develop a written standard operating procedure (SOP) during the week before actual testing. This activity provides valuable practice because an SOP is often required before approval is given to operate equipment in laboratory or manufacturing venues.

5. It recently has come [20] to the author's attention that while a standard test procedure apparently has not been formally established, nylon monofilament fishing line is typically tested wet (after soaking in tap water for two hours) using a gage length = 12 in. and a CHS = 10 in./min. Five specimens are evaluated for each test sequence. Nylon is water conditioned because its mechanical properties decrease [21] when exposed to water, and hence the attempt to simulate service life conditions. While water degrades mechanical properties, the slower CHS used in the current experiment should result in a lower strength because of nylon's strain rate sensitivity.

6. The first two specimen fixtures provide invalid experimental data but are included to allow students the opportunity to distinguish valid versus invalid test data, all obtained by computer and reported to four significant figures. The faces of wedge-action grips have a relatively sharp sawtooth profile that "bites" into the specimen to inhibit slippage during testing. However, the bare, small diameter line is significantly pinched by the grips creating a stress concentration, and the notch sensitive character of nylon is manifested by the fracture occurring at one of the grips with consequent artificially low fracture load. Tabs are attached with glue to isolate line from the grip faces during testing. While the approach accomplishes this objective, invalid data also results because the glue does not adhere to the line sufficiently well. An artificially low load is obtained since the filament pulls out of one of the tabs during testing before fracture can occur.

7. Fishing line can be readily viewed by taping it to the microscope stage in one or two places to keep it from moving while the stage is being manipulated. Transparent tape is suggested because adhesive residue is not left upon removal from the specimen or stage.

8. Long exposure times (on the order of 30 s) are required to obtain photomicrographs with illuminations other than brightfield. Spurious light entering the inverted objective lens can be avoided by turning off the overhead lights while the camera shutter is open.

9. The uncertainty in the elongation determinations is large because displacement was obtained indirectly from constant CHS rather than using the preferred technique of affixing an extensometer to the specimen, thus providing a direct measurement. Fortunately, the fracture strength of fishing line is of much greater interest than its strain capacity. However, an appropriate laser extensometer is available from Ametek (Chatillon) for small diameter fishing line specimens undergoing large extensions; in addition, an IR light extensometer suitable for such measurements is currently under development. [22]

REFERENCES:

[1] Flinn, R.A.; and Trojan, P.K.: Engineering Materials and Their Applications, 4th Edn., Houghton Mifflin Co. (now John Wiley and Sons, Inc.), 1990, p. 548.

[2] Evans, S. (Ed.): "Trout Fishing History and Lore," in Sports Afield Trout Fisher's Almanac: Expert Advice from America's Greatest Anglers, The Atlantic Monthly Press, 1997, pp. 1-29.

[3] Kalpakjian, S.: Manufacturing Processes for Engineering Materials, Addison-Wesley Publishing Co., 1991, pp. 650-652.

[4] Strong, A.B.: Plastics: Materials and Processing, 2nd Edn., Prentice-Hall, Inc., 2000, pp. 351-390 and 400-403.

[5] Dugger, A.: "Line Lotto: Different Lines for Different Needs," Sport Fishing, Volume 7, February 1992, pp. 70-77.

[6] Restivo, F.: "A Simplified Approach to the Use of Reflected Light Microscopes," Form No. 200-853 (1987), Leco Corporation, 3000 Lakeview Avenue, St. Joseph, Michigan, 49085.

[7] Vander Voort, G.: "The World Beyond Brightfield Illumination," Tech-Notes: Using Microstructural Analysis to Solve Practical Problems, Volume 1, Issue 3 (1997), Buehler Ltd., 41 Waukegan Road, Lake Bluff, Illinois 60014.

[8] Hertzberg, R.W.: Deformation and Fracture Mechanics of Engineering Materials, 4th Edn., John Wiley and Sons, Inc., 1996, pp. 298-303.

[9] Flinn, R.A.; and Trojan, P.K.: op. cit., p. 586.

[10] Flinn, R.A.; and Trojan, P.K.: op. cit., p. 93.

[11] Holman, J.P.: Experimental Methods for Engineers, 6th Edn., McGraw-Hill Book Co., 1994, p. 58.

[12] Flinn, R.A.; and Trojan, P.K.: op. cit., p. 88.

[13] Flinn, R.A.; and Trojan, P.K.: op. cit., pp. 560-561.

[14] Flinn, R.A.; and Trojan, P.K.: op. cit., pp. 661-663.

[15] Dugger, A.: "Break Point: We Test 50- and 30-Pound Lines," Sport Fishing, Volume 12, April 1997, pp. 48-54.

[16] Hertzberg, R.W.: op. cit., p. 276.

[17] Warner, S.B.: Fiber Science, Prentice-Hall, Inc., 1995, pp. 53-59.

[18] Zaukelies, D.A.: "Observation of Slip in Nylon 66 and 610 and Its Interpretation in Terms of a New Model," Journal of Applied Physics, Volume 33, September 1962, pp. 2797-2803.

[19] Karplus, A.K.: Knotty Knots, in National Educators' Workshop: Update 93, NASA Conference Publication 3259, 1994, pp. 369-372.

[20] Blodgett, D.: Telephone Conversation, International Game Fishing Association, Dania Beach, Florida 33004, May 17, 2000.

[21] Kalpakjian, S.: op. cit., p. 646.

[22] Critoph, A.: Telephone Conversation, Ametek, Largo, Florida 33773, November 9, 2000.

SOURCES OF SUPPLIES: Commercial-grade nylon monofilament fishing line is inexpensive and readily available at numerous retail stores from a variety of vendors. It is also possible that some fishing line manufacturers will supply complimentary small spools of test material and accompanying information. One such example is Pure Fishing Angler Service, 1900 18th Street, Spirit Lake, Iowa 51360, which sent upon request a student kit that contained the following: (1) 110-yd Berkley Trilene 10-lb test XL (extra flexible, smooth casting) line; (2) 110-yd Berkley Trilene 10-lb test XT (extra tough, abrasion resistant) line; (3) 100-page booklet entitled "Berkley: Catch More Fish"; (4) knot card; and (5) 7-page research paper entitled "Nylon Monofilament Fishing Lines".

ACKNOWLEDGEMENTS: Special thanks to Mark A. Elban for analyzing all of the experimental data leading to preparation of Tables I to III and A-I to A-III. Helpful discussion regarding the fracture behavior of nylon monofilament fishing line was provided

by Dr. Ronald W. Armstrong, Professor Emeritus, Department of Mechanical Engineering, University of Maryland, College Park, who not only has imparted to the author his wonderful enthusiasm for materials research but also his immense love for fishing, especially with dry flies. The identification of any manufacturer and/or product in this report does not imply endorsement or criticism by the author or Loyola College.

APPENDIX: A complete set of test data/results for Berkley Trilene 6-lb test XL line appears in Tables A-I to A-III that follow. (Instructor Note 1)

Table A-I. Force and Displacement Measurements for Berkley Trilene Six-Pound Test XL Nylon Monofilament Fishing Line

Specimen Fixture	Specimen Designation	Fracture Force* (lb_f)	Displacement at Break* (in.)	Comments
Wedge-action grips	T6XL1800	2.869	0.6430	Fractured at bottom grip; slightly kinked
	T6XL1900	3.886	0.8067	Fractured at top grip; slightly kinked
	T6XL2000	2.441	0.4327	Fractured at top grip
	T6XL2100	2.238	0.4090	Fractured at top grip
	T6XL2200	2.970	0.5076	Fractured at top grip
	T6XL2300	3.479	0.5418	Fractured at top grip; slightly kinked
	Avg.:	**2.98 [13.3 N]**	**0.557**	
	σ:	**0.62 [2.8 N]**	**0.15**	
Wedge-action grips with cardboard tabs	T6XL2400	3.153**	0.6178**	Pull out at bottom tab
	T6XL2500	2.991**	0.7186**	Pull out at bottom tab
	T6XL2600	3.398**	0.8527**	Pull out at bottom tab
	T6XL2700	2.604**	0.7490**	Pull out at bottom tab
	T6XL2800	3.316**	0.6783**	Pull out at bottom tab
	T6XL2900	2.543**	0.6181**	Pull out at bottom tab
	Avg.:	**3.00 [13.3 N]**	**0.706**	
	σ:	**0.36 [1.6 N]**	**0.089**	
Bollard grips double wrapped	T6XL0600	7.934	2.900	Fractured in middle; kinked
	T6XL0700	7.751	2.703	Fractured in middle; kinked
	T6XL0800	7.792	2.711	Fractured in middle; kinked
	T6XL0900	7.833	2.587	Fractured in middle; kinked
	T6XL1000	7.609	2.588	Fractured in middle; kinked
	T6XL1100	7.527	2.491	Fractured in middle; kinked
	Avg.:	**7.74 [34.4 N]**	**2.66**	
	σ:	**0.15 [0.67 N]**	**0.14**	

Table A-I. Force and Displacement Measurements for Berkley Trilene Six-Pound Test XL Nylon Monofilament Fishing Line, Cont'd.

Specimen Fixture	Specimen Designation	Fracture Force* (lb_f)	Displacement at Break* (in.)	Comments
Bollard grips double wrapped with filament knot	T6XL1200	4.110	1.647	Fractured at knot; kinked
	T6XL1300	5.005	1.744	Fractured at knot; slightly kinked
	T6XL1400	4.557	1.675	Fractured at knot; slightly kinked
	T6XL1500	5.371	1.811	Fractured at knot; kinked
	T6XL1600	2.746	1.193	Fractured at knot
	T6XL1700	3.682	1.418	Fractured at knot; slightly kinked
Avg.:		**4.25 [18.9 N]**	**1.58**	
σ:		**0.95 [4.23 N]**	**0.23**	

* Obtained from computer analysis of force-displacement curve.

** Maximum force reported rather than fracture force since filament pull out occurred rather than fracture; displacement at maximum force reported rather than at break for the same reason.

Table A-II. Mechanical Property Results for Berkley Trilene Six-Pound Test XL Nylon Monofilament Fishing Line

Specimen Fixture	Specimen Designation		Fracture Strength (psi) [MPa]	Elongation at Break (%)
Bollard grips double wrapped	T6XL0600		129,000 [888]	61
	T6XL0700		126,000 [867]	57
	T6XL0800		132,000 [912]	57
	T6XL0900		133,000 [917]	54
	T6XL1000		129,000 [890]	54
	T6XL1100		122,000 [842]	52
		Avg.:	**128,000 [886]**	**56**
		σ:	**4100 [28]**	**3**

Table A-III. Specimen Diameter Results for Berkley Trilene Six-Pound Test XL Nylon Monofilament Fishing Line

Specimen Fixture	Specimen Designation	Initial Diameter (mm)	Final Diameter (mm)		Change in Diameter (mm)
Wedge-action grips	T6XL1800	0.225	0.225		0.00
	T6XL1900	0.23	0.225		-0.005
	T6XL2000	0.225	0.225		0.00
	T6XL2100	0.225	0.225		0.00
	T6XL2200	0.225	0.225		0.00
	T6XL2300	0.225	0.225		0.00
				Avg.:	**-0.001**
				σ:	**0.002**
Wedge-action grips with cardboard tabs	T6XL2400	0.225	0.225		0.00
	T6XL2500	0.23	0.225		-0.005
	T6XL2600	0.23	0.23		0.00
	T6XL2700	0.23	0.225		-0.005
	T6XL2800	0.225	0.225		0.00
	T6XL2900	0.225	0.225		0.00
				Avg.:	**-0.002**
				σ:	**0.003**
Bollard grips double wrapped	T6XL0600	0.225	0.22		-0.005
	T6XL0700	0.225	0.22		-0.005
	T6XL0800	0.22	0.22		0.00
	T6XL0900	0.22	0.22		0.00
	T6XL1000	0.22	0.225		0.005
	T6XL1100	0.225	0.22		-0.005
				Avg.:	**-0.002**
				σ:	**0.004**

Table A-III. Specimen Diameter Results for Berkley Trilene Six-Pound Test XL Nylon Monofilament Fishing Line, Cont'd.

Specimen Fixture	Specimen Designation	Initial Diameter (mm)	Final Diameter (mm)	Change in Diameter (mm)
Bollard grips double wrapped with filament knot	T6XL1200	0.225	0.22	-0.005
	T6XL1300	0.225	0.225	0.00
	T6XL1400	0.22	0.22	0.00
	T6XL1500	0.225	0.225	0.00
	T6XL1600	0.225	0.22	-0.005
	T6XL1700	0.22	0.22	0.00
			Avg.:	**-0.002**
			σ:	**0.003**
Overall Avg.:		**0.225**		
σ:		**0.003**		

EARTHQUAKES, MATERIALS AND AN EDIBLE VILLAGE: AN EDUCATIONAL EXPERIMENT FOR HIGH SCHOOL STUDENTS

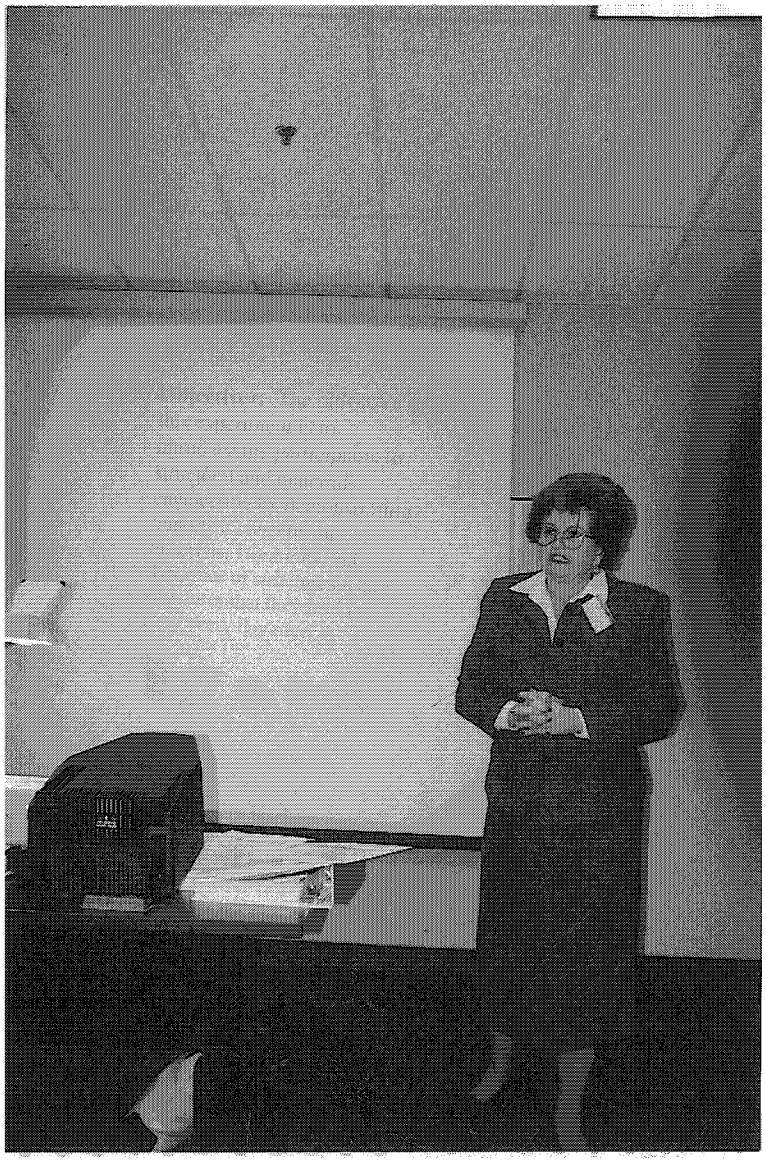
Neda Fabris

Mechanical Engineering Department
California State University, Los Angeles
5151 State University
Los Angeles, California 90032

Telephone 323-343-5218
e-mail nfabris@exchange.calstatela.edu

Biographical Information:

Neda Fabris has taught at Cal. State LA since 1979. She teaches classes in manufacturing, materials, mechanics and design. She holds a Master of Engineering degree from the University of Sarajevo, Bosnia, and a M. S. and Ph.D. from Illinois Institute of Technology Chicago Ill, and was a postgraduate researcher at Technishe Hoch Schule in Aachen, Germany. Her recent awards include the Society of Manufacturing Engineers "Distinguished Manufacturing Educator" award of Region 12 (Southwest U.S.) in 1998 and the "First Cal State LA Distinguished Women Achievement Award" in 1999. She has contributed several times to this conference.



Earthquakes, Materials and an Edible Village: An Educational Experiment for High School Students

Neda Fabris
California State University Los Angeles
Los Angeles CA 90032

Abstract: This paper describes hands on experiments that demonstrate the influence of soil, construction material and a structure's shape and size on the performance of a building during earthquakes. Participants in the experiment build structures from toothpicks, marshmallows, breadsticks and gummy balls and place them on the two containers with different types of "soil". "Soil" is made from clay to represent bedrock and from gelatin to represent landfill. The containers are then shaken manually, simulating an earthquake, while participants observe the behavior of different structures. The experiments are fun, as well as educational, and are suitable for outreach activities and demonstrations of structural design principles in the "Introduction to Engineering" class.

Key Words: Natural Frequency, Stiffness, Mass, Resonance

Prerequisite Knowledge: A basic knowledge of algebra and physics as well as a curiosity to understand what causes some structures to withstand earthquakes better than others do.

Objectives: The objective of this experiment is to introduce the participants to structural and materials engineering by demonstrating important concepts in materials, vibrations and dynamics of structures using structures that they build from every day objects.

Equipment and Materials: No special equipment is necessary. The amount of material used is dependent upon how many groups of participants there are. The list of material below is based on one group and has to be multiplied by the number of groups.
We like to team four-five people in one group.

1. 2 pounds of firm artist clay
2. 2 large packages gelatin dessert
3. 2 package unflavored gelatin
4. Boiling water
5. Box of toothpicks
6. 1 pound marshmallows
7. 1 pound of Jelly Drops ("Spice Drops") or gummy balls
8. 1 pound of breadsticks
9. 9"x 6" container

Safety Precautions: The only possible problem with this experiment is the mess created by spilling gelatin during the preparation period, as well as a temptation to eat, throw and play with "structural elements."

Introduction

This experiment was developed for the "All Geared Up" Girl Scout Engineering Program in February 2000. It was also performed several times by the participants of the "Mother-Daughter" Academy at California State University, Los Angeles during spring and summer 2000. The experiment was very well received, due to its interactive components and simple but insightful explanation of the common phenomena in Los Angeles: earthquakes. Participants worked in teams, used their own creativity and had fun while learning several engineering and scientific concepts.

Theoretical Background

Earthquake waves propagate through the ground with a frequency between 0-20 HZ. The structure that has a first natural frequency in that range will be prone to resonance, causing extensive damage. To avoid resonance, high amplitude shaking and potential damage, the goal of engineers is to design and build structures with a natural frequency that is higher than the range of an earthquake frequency.

First natural frequency f of the undamped single degree-of-freedom system of mass m and stiffness k can be expressed as[1]:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \qquad (1)$$

Where: k is the stiffness in lb./in. or N/m.
m is the mass in lb. mass or kg

Natural frequencies of the undamped, lumped parameter system with more then one degree of freedom is given by a similar equation

$$f = \frac{C}{2\pi}\sqrt{\frac{k}{m}} \qquad (2)$$

Where C is the function of number of degrees and ratio of mass and stiffness of each degree of freedom in the system. For example, for the three degree-of-freedom system, consisting of three equal masses m and three equal springs k: C=0.445 for the first, 1.25 for the second and 1.80 for the third natural frequency[2].

Although structures are continuous systems with some damping properties, this simplified model is often used in engineering studies and works very well for introducing

participants to the most important factors in structural and seismic design, which can be summarized as:

A structure with a small mass (weight) and a high stiffness has a high natural frequency. If that frequency is above an earthquake frequency the building will not resonate during earthquakes and it will not sustain substantial damage.

High stiffness in a structure is achieved by using building materials with higher modulus of elasticity (like steel or reinforced concrete) or material with low weight like wood. Heavy materials (stone, brick and concrete blocks) which are connected to material with low stiffness, is forbidden for structural use in earthquake prone areas.

Naturally, stiffness of the support (type of ground and anchoring of the structure) as well as the shape, size and design of a structure, play an important role in the actual stiffness of the structure.

Experimental Demonstrations

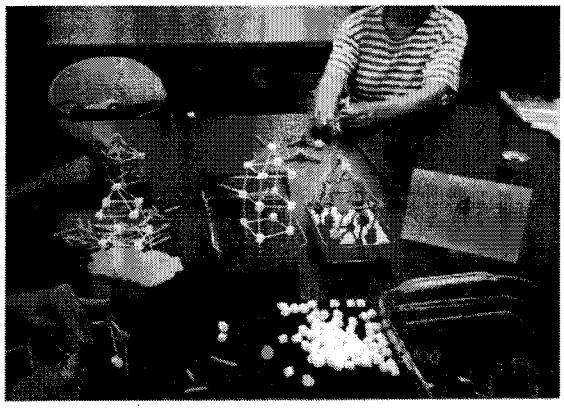
In order to demonstrate concepts discussed above, we prepared in advance the "soil" for the experiments: a " bedrock" plate made from clay in the container and "landfill" soil made from gelatin. Gelatin dessert and unflavored gelatin were mixed together and prepared according to directions for the gelatin dessert to make thicker gelatin that is less prone to softening during the experiment. Using double amounts of gelatin desserts but using 50% less water can produce a similar effect. The mixture is poured into a 9x6 Plexiglas baking pan and cooled overnight. For this experiment gelatin must be at least 1 in. deep.

We provided participants with both trays and with boxes of toothpicks, marshmallows, jelly drops and bread sticks. Participants also received instructions as reproduced below.

Participants had fun making one-story, two- and three- story building of different shapes, sizes and from different material, as seen from the pictures below. We placed the buildings on the clay and gelatin "soil" and then shook the containers, simulating earthquakes, while we observed the damage that the buildings sustained.

In this experiment, participants have learned fast that:

- Buildings made with marshmallows sustain less shaking then those made with gummy drops (difference in stiffness)
- A one-story building is more resistant to shaking than a three-story building
- Pyramids shapes provide for the stiffest structures
- Buildings on a clay support can sustain more shaking than buildings on gelatin
- You can increase the stiffness of a building by bracing it with diagonal sticks



Work Sheet Given To Students

The following instructions were given to participants.

A. Earthquake Performance of Structures

Goal: The goal of the workshop is to demonstrate the influence of the type of soil (earth), as well as buildings' size, shape and materials on the stability and endurance of structures during earthquakes.

In Southern California we have all experienced earthquakes. We have also witnessed that some buildings and structures fall apart, while others remain intact. Why does this happen?

In this workshop we will investigate three important factors that influence the behavior and endurance of structures:

1. *Type of soil on which buildings are located:*
   To demonstrate the effect of the ground on the integrity of structures, we will make a "three-story building" from toothpicks and marshmallows, connecting toothpicks with marshmallows in each corner. We will erect and shake this "building":
   a) on clay (which represents bedrock)
   b) on the tray with gelatin (which represents landfill)

   What did you observe? Which building will survive better? What cities were damaged the most during the 1994 Northridge earthquake? Did the cities built in the valleys (landfills), like Northridge, or the cities built on the hills (bedrock), likes Beverly Hills, sustain the most damage?

2. *Size of the building*
   Using toothpicks and marshmallows, make four buildings: one single-story, one two-story, one-three stories and one four-story high. Put all of the buildings "landfill" (tray with gelatin) and shake.

What did you observe? Which building survives best, and why? The more stories a building has, the more the shaking is amplified. Where would you feel an earthquake more, in a ranch house or in a skyscraper?

3. *Shape of the building*

Using toothpicks and "edible" construction elements (breadsticks, marshmallows, and gelatin candies), construct buildings of different sizes and shapes (cube, pyramid and others, be creative).

Which shape survived the "earthquake" best? Can you guess why pyramids are several thousands of years old?

4. *Influence of the material used in building the structure*

Makes a one-story "building" from breadsticks and marshmallows and an other with breadsticks and jelly candies (roughly the same size and shape).

Which one of your materials, a marshmallows or jelly candy, is stronger and stiffer? Which one survived the earthquake better?

Note: The earth shakes at the relatively low frequency of 0-20 HZ (cycles per second). A building should be designed to have a higher natural frequency (the frequency when it vibrates with largest amplitude) than the frequency of the ground so that it does not resonate with the ground (resonance amplifies the vibration). The natural frequency of a one-story building is proportional to the square root of the stiffness divided by its mass. That means: buildings with low stiffness and large mass do not withstand earthquakes very well (like those made from heavy stones or bricks with not so stiff cement connections), while the buildings made from strong and stiff material, like steel or light wood, survive earthquakes very well.

B. Design of an Earthquake Resistant Edible "Village"

When you have learned and understood all of the above, make a village from "edible" building elements (i.e. breadsticks, marshmallows, jelly beans) that will, in your opinion, survive the earthquake the best. Your village should consist of five buildings, no two exactly the same. We will test each village for earthquake survival on the gelatin tray.

Let's see who's village will be the best! The best group of designers will be recognized as the most promising civil engineers. Good luck!

After the buildings were finished, we helped students place the structure on gelatin and clay bases and then shook the containers to simulate earthquakes.

Discussion and Conclusions

In addition to being fun this experiment was an educational experience for participants, and it demonstrated to the students several important physical concepts. The idea for this workshop came from my daughter's science textbook, which she used to teach high school science.[3] In the textbook, the experiments were conducted with only identical types of "buildings": three-story buildings made from toothpicks and marshmallows and placed on two different types of ground. I have expanded the concept, using different building materials and shapes and added the explanation of the underlining theory in simplified terms. My high school student assistant was instrumental in suggesting material for the buildings (Gummy Drops, breadsticks).

For the Girl Scouts Engineering Day, we expected 200 participants. My volunteer assistants, mostly engineering students and members of the Society of Women Engineers, and I made 15 trays of gelatin, making a big mess in our homes. Actually, we did not need so many trays, since we had only approximately100 participants, so we used the same tray for several groups of students.

The workshop was very well received by students, girl scouts chaperones and helpers, who were quite intrigued to see how earthquake' damage can be simply demonstrated and explained.

We conducted this experiment during different sessions of, my "Mother-Daughter" workshops, where the reception was also very good. The experiment was also featured in the local newspapers. This time we made only four trays of gelatin.

References:

1. Steidel R.F. Jr, An Introduction to Mechanical Vibrations, (3rd ed.), J Wiley & Sons, New York, 1989
2. Harris C.M. and Crede E.C. (Editors), Shock and Vibration Handbook (2nd ed.), McGraw-Hill, New York, 1975
3. Aldridge B. and al. Science Interactions (Course 1), Macmillan/McGraw-Hill, New York, 1993

Acknowledgment:

I would like to thank my daughter, Nicole Fabris, who is a student in the New York Medical College, for introducing me to this experiment and helping with its execution. Also my thanks goes to Lisa Grosskopf-Boutwell and Linzi Boutwell for constructive suggestions and organization of a Girl Scouts Engineering Day. I am especially thankful to NSF, Division of Human Resource Development, for sponsorship of the "Mother-Daughter Academy".

DATA REPORTING AND ANALYSIS IN SCIENCE AND ENGINEERIING COURSES

John P. Elwood
and
Shingara S. Sandhu

Clafin University
400 Magnolia Street
Orangeburg, South Carolina 29115

Telephone: 803-535-5242

Data Reporting and Analysis in Science and Engineering Courses

Dr. John P. Elwood
Department of Chemistry
Claflin University
Orangeburg, SC 29115
USA

Dr. Shingara S. Sandhu
Department of Chemistry
Claflin University
Orangeburg, SC 29115
USA

Abstract:

This workshop explores and demonstrates techniques for fully incorporating professional data reporting and analysis into upper level science and engineering courses. The methods use basic spreadsheet and graphics software packages.

A terrible disparity is often found between what science and engineering students learn about computers arid what they use them for. The authors have found this opinion to be common to a large number of other faculty members. Data storage, analysis, and presentation are essential to the success of a research scientist. These tasks can all be performed with one software package, the modern-day spreadsheet. The use of the spreadsheet for these tasks also reinforces such non-computer concepts as dependent variable, independent variable, statistics, parameter, regression analysis, graphs, outliers, etc.

The authors, from many years of practical experience, have also found it useful to separate data up into such categories as physical constants, configuration data, environmental data, and run data. Of course, the workshop will also discuss, in a very applied fashion, such other concepts as spreadsheet functions, derived data, unit specification, essential components of graphs, etc.

Many advanced instruments today do come with these capabilities built in. However, it is not clear that the student appreciates the value of such features or would be able to develop such systems for an in—house experimental setup. These techniques and principles are now being used quite successfully in the authors' Physical Chemistry and Analytical Physical Chemistry courses.

Key Words: Data storage, Data Analysis, Dependent Variable, Independent Variable, Statistics, Parameter, Regression Analysis, Graphs, Outliers, Spreadsheet Functions, Derived Data, Unit Specification

Prerequisite Knowledge: Basic knowledge of computer spreadsheets and functions. That is, entry of labels, numbers, formulas, functions, etc. Prior experience performing scientific experiments and preparing laboratory reports.

Objective: To understand the method of analyzing and presenting experimental data using standard computer software packages.

Equipment and Materials:

1. DOS or Windows base computer
2. DOS 6.0 or higher or Windows 95 or higher operating system
3. Lotus 3.0 or higher or Excel 97 or higher spreadsheet package
4. Graphics capable printer
5. Apparatus for experiment being recorded and analyzed

Safety Precautions:

As required for experiment being recorded and analyzed

Introduction:

The need for instruction in the use of spreadsheets for data storage, analysis, and presentation became apparent to the authors from two different facets of their work in an academic setting – research and teaching.

The need to prepare data for technical presentations is obvious to research scientists. In reporting work done at Claflin on the high temperature combustion of halogenated hydrocarbons, the authors developed spreadsheets that served the multiple purposes of storing data, performing statistical analysis, and yielding presentation data tables and presentation graphics. Samples of these are included in references 1 and 2.

It also became apparent that a template could be prepared on which to store and analyze data for different runs. The analysis and graphical presentation was almost identical for all runs. In fact, much identifying data, such as sample formula, background gas, and date, could be automatically inserted into titles, legends, and other text.

The above considerations indicate a need for Run Data (partial pressures and absorbance) and Environmental Data (temperature, sample name, background gas, and atmospheric pressure). However, the apparatus used included a state-of-the-art, gas phase FTIR spectrophotometer. This unit not only had temperature control, but also two different sample cells – one with a 10 cm optical path length and one with a 10 m optical path length. These two cells had not only different optical path lengths but also different volumes. The volume of gas sample per se does not enter into the calculations (essentially the Beer-Lambert Law) but does create significantly different manifolding (tubing and valve) requirements. Thus the need for Configuration Data (optical path length, tubing length, tubing diameter) appeared.

The wide range of sample gas partial pressures (concentration) used created small inaccuracies in final concentrations due to changes in the levels of mercury in the arms of the manometers. (Pressure measurements were made with simple mercury manometers – one closed-ended for low sample concentrations and one open-ended for total pressure near atmospheric.) Formulas were entered into the spreadsheet to make first-order corrections for these changes assuming the Ideal Gas Law. Hence a data section was created to hold Physical Constants (gas constant).

At the same time that the authors were conducting the research described above, they were teaching in the rapidly expanding Department of Chemistry at Claflin University. More students of ever increasing capabilities and aspirations were enrolling in the sciences at Claflin. (A major stimulus in recruitment resulted from grants received by Dr. Sandhu, in some cases with Dr. Elwood, for pre-college programs.) It was noted, however, that as today's students absorb the ever-increasing number of scientific principles, theories, and concepts, they may lose track of some of the seemingly obvious questions:

What is a large number?
What is a small number?
Are a series of points in a straight line?

It almost seems as if the evolution from slide rule to calculator to computer has taken away the need for efficiency and dexterity in the use of numbers. For example, a student might enter the temperature in Celsius in one column, then calculate the temperature in Kelvin by hand and enter this in another column

Thus it was decided to as much as possible utilize spreadsheets and derived graphics in laboratory sessions of advanced chemistry courses. These would be similar to the spreadsheets and graphs utilized in the research mentioned above.

Experimental:

Figure 1 shows an early version of the gas phase FTIR apparatus. The much more complex manifolding system developed later is shown in Figure 2. Figure 3 is a spreadsheet developed for this research. It varies slightly from the description under **Introduction** above in that Environmental Data is labeled BASELINE DATA and there is no section for Physical Constants. Figure 4 is the graph generated by the spreadsheet in Figure 3.

Figure 5 shows a spreadsheet that adheres rigidly to the standards set up for coursework. It goes with an experiment on the use of the Gas Chromatograph. Figure 6 is the graph which is generated by the spreadsheet in Figure 5.

The following specifics should be pointed out:

1. Wherever possible, data is calculated by spreadsheet formulas (e.g. temperature in K and Concentration in % by Volume).
2. Units are always shown, and in separate cells from the data.

3. Powers of 10 are included with units when necessary to make cell entries reasonable numbers.
4. Titles of spreadsheet and graph include entered data by way of concatenated text.
5. A spreadsheet regression function is used to estimate the Extinction Coefficient, the essential output of the experiment.
6. Best-fit straight lines are shown on the graph.
7. A value for R^2 or other statistical test of fit is usually given.

Results:

Fig. 6 shows that the peak area is directly proportional to Concentration as a % by volume. This relationship is linear. Furthermore the best straight fit line appears to go through the origin. Both peaks show the same linear relationship to concentration but with different extinction coefficients.

Conclusions:

1. The spreadsheet serves the multiple purposes of storing, analyzing, and presenting experimental data.
2. The graph generated provides a clear illustration of the relationship between peak area and concentration.
3. The spreadsheet and graph give a view of the "quality" (accuracy and precision) of the experiment so the student can determine whether or not it needs to be repeated and what improvements might be made.

References:

1. Shingara S. Sandhu, John P. Elwood and Jenee' Robinson, "Mechanism for *In Situ* Measurement of Laser Ablated Polymer Transient Species," 215th ACS National Meeting, American Chemical Society, March 30, 1998.
2. Shingara Sandhu, John Elwood, Terry Green, LaKeana Jones and Melviena Miller, "FTIR Analysis of Gaseous Products from Hazardous Waste Combustion," Northeast Hazardous Substances Research Center, Cambridge, Massachusetts, November, 1995.
3. Excel 8.0 with Curriculum Integration, Teacher Universe, Inc., Raleigh, NC, 1999.

Biographical Information:

Dr. John Elwood obtained his B.A. degree in chemistry from Northwestern University, Evanston, Illinois, in 1966. He completed a Ph.D. degree in physical chemistry at Massachusetts Institute of Technology in 1971. His major research interests rest on intermediary products of the combustion of halogenated hydrocarbons. He is a
member of the American Chemical Society. He is currently an associate professor and Chair of

the Department of Chemistry at Claflin University, Orangeburg, SC, USA.

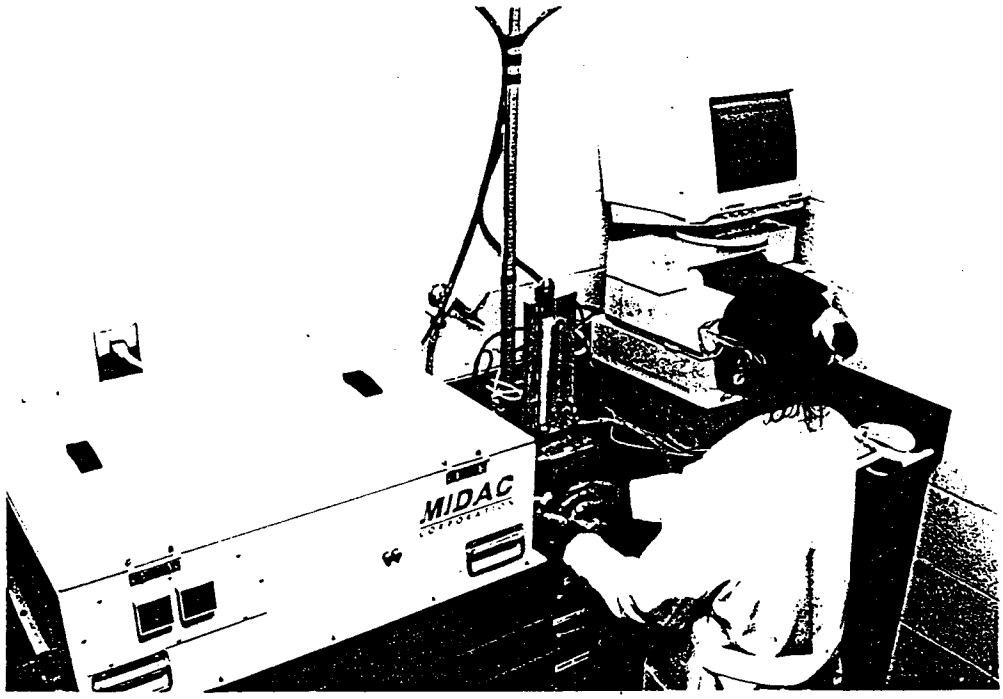
Dr. Shingara Sandhu obtained his B.S. and M.S. degrees in chemistry from Punjab University, India. He completed a Ph.D. degree in environmental chemistry at Utah State University. His major research interests rest on analytical techniques for determination of heavy metals in environmentally important substrates and the movement of metals in soils. He is a member of the American Chemical Society. He is currently a full professor and Director of Grants and Research at Claflin University, Orangeburg, SC, USA.

Dr. Sandhu has received numerous professional awards from around the world. He was selected as the South Carolina Governor's Professor of the Year in 1996. Dr. Sandhu has authored over 50 publications in both domestic and international journals and has spoken at over 20 scientific conferences.

Acknowledgment:

This work was performed at the Department of Chemistry , Claflin University, with partial support from the U.S Environmental Protection Agency and from the U.S. Department of Energy.

Figure 1. Gas Phase FTIR Apparatus



Quantitative Analysis of CH4
In Nitrogen Background at 24.0 C

Date of Report	10/13/95	FILE:	090895AA
Time of Report	15:25		

BASELINE DATA

Date Run:	9/8/95
FTIR cell:	ambient
Sample:	CH4
Background:	Nitrogen
Atmo.Mano.:	835
Vacu.Mano.:	101.1
Temp (C/K):	24 297.1
Atmo.Press:	754.9

CONFIGURATION DATA

Cell:	Length:	10.00	Diameter	4.45	
Vacu.Man:	Diameter:	0.39	Area:	0.12	
Atmo.Man:	Diameter:	0.50	Area:	0.20	
Rubb Tbg:	Diameter:	0.64	Area:	0.32	
SS Tubng:	Diameter:	0.18	Area:	0.02	
Volumes:	Vac. side	91.82	Gas side	32.98	
Cell:		155.53	Total:	280.33	

RUN DATA

			Area 1		Area 2	
		Upper Wavelength	3200		1600	
		Lower Wavelength	2600		1200	

Run No.	Resid'l mmHg	Fill mmHg	Sample mmHg	mol/L X E -3	Experimental	Estimated	Experimental	Estimated
1	5	25	20	1.05	3.06	3.33	1.98	2.30
2	5	38	33	1.73	4.81	5.51	3.66	3.80
3	5	51	46	2.42	8.84	7.69	5.20	5.31
4	5	62	57	3.00	9.34	9.54	6.64	6.59
5	5	72	67	3.53	11.70	11.23	7.62	7.75
6	5	84	79	4.17	12.70	13.26	9.44	9.16
				0.00		0.00		0.00

Area 1
Regression Output:

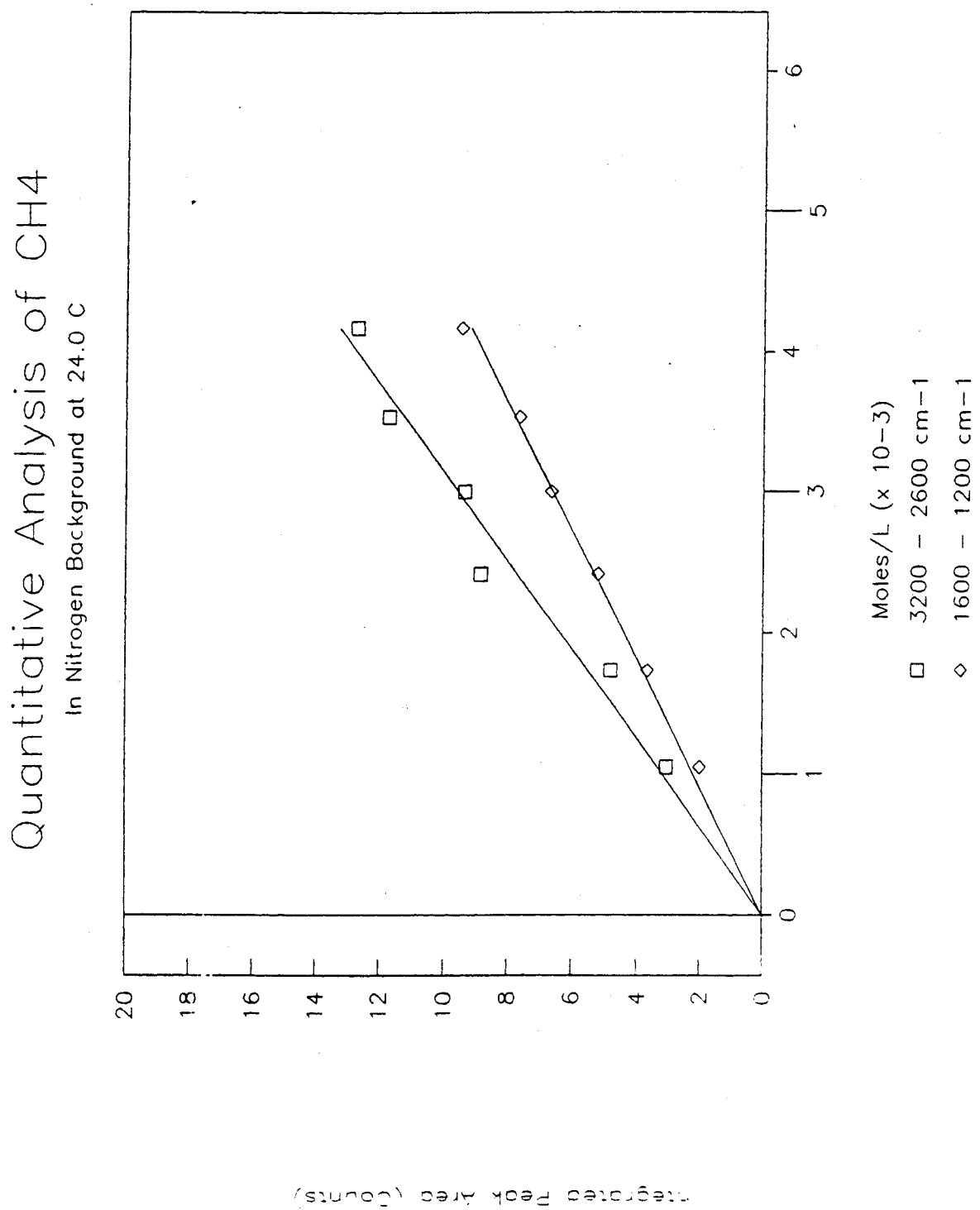
Constant	0
Std Err of Y Est	0.701171
R Squared	0.965791
No. of Observations	6
Degrees of Freedom	5
X Coefficien	3.18
Std Err of C	0.10

Area 2
Regression Output:

Constant	0
Std Err of Y Est	0.218652
R Squared	0.993502
No. of Observations	6
Degrees of Freedom	5
X Coefficient(s)	2.20
Std Err of Coef.	0.03

Figure 3. Spreadsheet Used in Gas Phase FTIR Research

Figure 4. Graph Generated from Gas Phase FTIR Research



Quantitative Analysis of Diesel Fuel
In Iso-octane Solvent at 25 C

Experiment Name:	Gas Chromatography - Diesel Fuel Calibration
Date of Report:	10/18/2000
Date of Run:	01/11/1999
Student Name:	John Elwood
File:	LAB_911.XLS

PHYSICAL CONSTANTS

Gas Constant:	R	8.315 J K-1 mol-1
Absolute Temperature:		273.15 K

CONFIGURATION DATA

Column:	30 m x 0.53 mm cross-linked polydimethylsiloxane
Method:	FID1
Detector:	Flame ionization

ENVIRONMENTAL DATA

Background:	Iso-octane
Temperature:	25 C
Temperature:	298.15 K

RUN DATA

Sample: Diesel Fuel

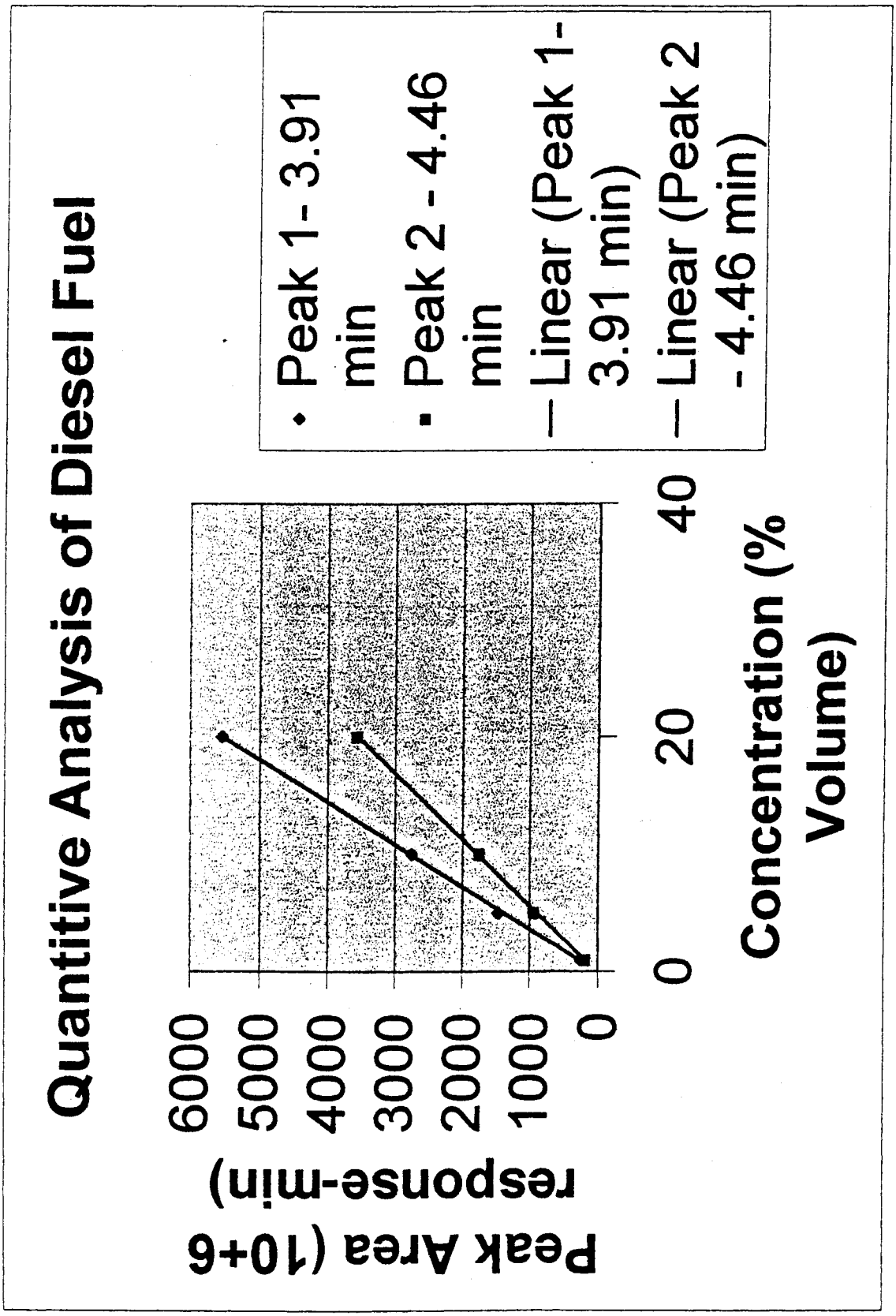
				Peak 1		Peak 2	
			Retention Time	3.91 min		4.46 min	
				Peak Area (10+6 response-min)			
Run No.	Sample (mL)	Solvent (mL)	Concentration (% by volume)	Exp 1	Pred 1	Exp 2	Pred 2
1	1	99	1	254.8	277.6	186.1	178.0
2	5	95	5	1475.7	1387.8	939.7	889.9
3	10	90	10	2753.2	2775.5	1744.5	1779.8
4	20	80	20	5541.4	5551.1	3564.4	3559.6
			0		0.0		0.0

Integrated Volume % Extinction Coefficient
(10+6 response-min vol%-1)

Peak 1	Peak 2
277.6	178.0

Figure 5. Spreadsheet for Gas Chromatography Experiment

Figure 6. Graph Generated from Gas Chromatography Experiment



A REMOTE EXPERIMENT FOR CLASSROOM USE

Richard B. Griffin
Mechanical Engineering

Carlos L. Yapura
Aerospace Engineering

and

Dimitris C. Lagoudas
Aerospace Engineering

Texas A&M University
College Station, Texas 77843

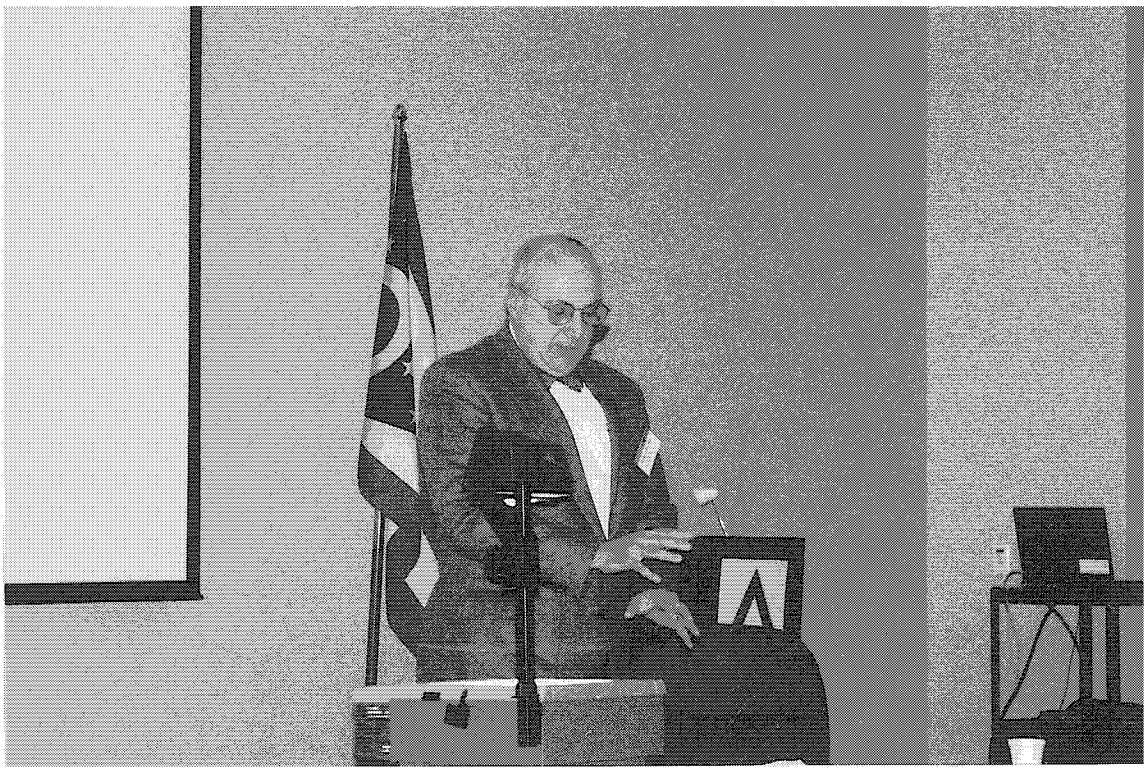
Telephone 979-845-9779
e-mail RGriffin@mengr.tamu.edu

Biographical Information:

Dr. Richard B. Griffin has been at Texas A&M in Mechanical Engineering since 1977. His research area is aqueous corrosion, and he received a NACE Technical Achievement Award in 1992. For the past six years, he has been a member of the Sophomore Team-Foundation Coalition that developed the core engineering science courses, which have been adopted at Texas A&M University.

Carlos Yapura is a recent Ph. D. graduate of Aerospace Engineering at Texas A&M University. Currently, he is the test engineer at the low speed wind tunnel Texas A&M University.

Dimitris Lagoudas is a faculty member in Aerospace Engineering at Texas A&M University. He has been Co-Team Leader for the sophomore year program. His research interests are composite materials, and currently, he is the director of the Smart Materials Institute at Texas A&M University.



Richard B. Griffin

A Remote Experiment for Classroom Use

Richard Griffin,
Mechanical Engineering

Carlos L. Yapura,
Aerospace Engineering

Dimitris C. Lagoudas,
Aerospace Engineering

Texas A&M University
College Station, TX 77843

Abstract:

Students have a variety of learning styles, for many, it is essential in the learning process to experience the subject matter being discussed in class. However, with large class sizes (60- 80 students per section) it is not always possible to have students perform experiments. As a result, a remote-site experiment has been developed for use in the classroom that uses a testing machine capable of tension, compression, and torsion.

Using the knowledge developed from discussions of the elastic behavior of materials, a torsion experiment has been implemented. The test may be run from computers located in the classroom, where students collect data, and analyze it using the classroom computers. The testing machine is located in another building on campus. A description of the process will be given in the paper.

Key Words:

Mechanical properties, remote testing, testing, experiments, and torsion

Prerequisite Knowledge:

Physics, mathematics, chemistry, and elastic behavior of materials

Objective:

To develop remote experiments via the Internet that realistically demonstrate the various principles of material behavior taught at the sophomore engineering level to a large number of students, who do not have access to a laboratory facility.

Equipment and Materials:

Uniaxial testing machine, specimens, LabView®, Data Socket, camera, internet connection, computers connected to the internet.

Introduction:

The experiment to be described was pilot tested using sophomore level engineering students at Texas A&M University as part of the NSF Foundation Coalition effort to restructure the sophomore level engineering courses.[1] Since these courses are taught to a large number of the engineering students, and because the time allowed for

laboratory activities in a sophomore level class was limited, the method of delivery of these labs was of primary importance.[2] During the fall 1998 semester, the testing machine was actually rolled to the classroom and four class sections each of about 60 students were divided in teams of eight students and each team ran a tension test. From the students' point of view, obtained from evaluation comments, the principal advantages of the team laboratory activities included hands-on experience and being able to connect the material learned in the lectures with a practical testing application. On the other hand, the limited time available resulted in only a few members per team having a chance to participate in the actual experimentation, confusion in the data reduction, too much work in a short period of time, and too many students per experimental apparatus. Many of the mentioned disadvantages were addressed by considering remote experimentation using LabVIEW. During the spring 1999 semester, students were able to remotely run tension tests and obtain data in a time-efficient manner. This paper will describe the development of a torsion experiment using the same basic equipment.[3]

Procedure:

The experiments developed were carried out using an Adelaide Testing Machine (ATM), equipped with computer-controlled loading and data acquisition systems. The testing machine is shown in Figure 1.

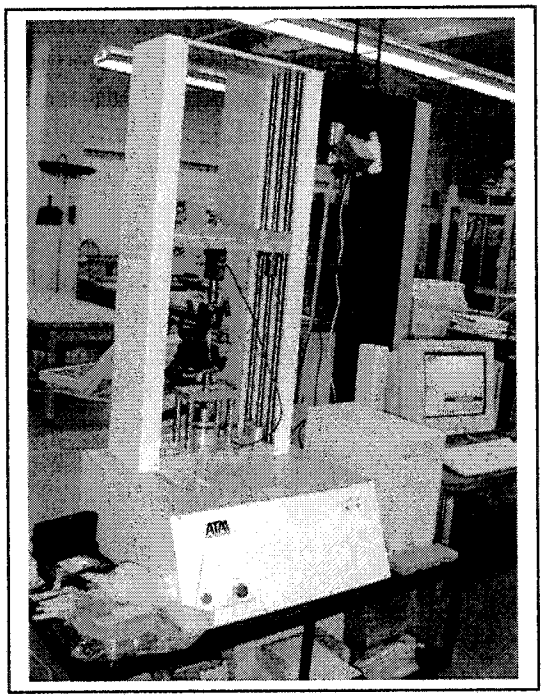


Figure 1. ATM Test frame used for tension, compression, and torsion tests.

The ATM is capable of testing specimens in tension, torsion, and compression. The unit is controlled with a PC through two XT-type cards. One card is an *Analog/Digital (A/D) converter* from ATM, Inc. which acquires voltage readings from the *axial load cell*, the *torsion load cell*, and the *extensometer*. The extensometer is used to obtain strain measurements on a fixed reference length of 1 in. The voltage readings from the A/D

card are then converted at the software level into pounds (lb.) for the axial load measurements, in-lb for the torque measurements, and in/in for the strain measurements.

The other card is a *servo-controller card* from *Galil Motion Control, Inc.* that is used to send commands to the servomotors of the ATM. The servomotors move the crosshead vertically for axial testing and rotate the lower jaw grip for torsion testing. This card also detects encoder counts to give the axial displacement of the crosshead during tensile/compressive loading and the rotation of the jaw grips during torsion testing. The ATM was originally set to operate using an *MS-DOS program* from ATM, Inc.

It was not possible to run a test in a remote experiment mode using the available MS-DOS software, and therefore LabVIEW was adopted. Fortunately there were existing LabVIEW drivers for the Galil servo-controller card available from the Galil Motion Control's Website. The A/D card did not have existing LabVIEW drivers but this memory-based card was easily accessed by using the InPort/OutPort VI's available in LabVIEW. Technical information about the A/D card was obtained from ATM, Inc. Once the drivers were written, LabVIEW provided a framework where a test could be customized according to a required experiment. That is, a VI was created where a deformation history was specified by sending the corresponding commands to the servomotors. This VI provided the advantage that it could be easily modified to specify any deformation history composed of axial and rotational motions. The deformation data and the tensile, compressive, or torsion data were then recorded during the time period when the servomotors were set in motion.

Comments:

Once the ATM was set to be controlled with LabVIEW and with the recent development of the DataSocket application, a remote experiment was readily implemented. This time the ATM did not need to be rolled into the classroom. The ATM and the controller/server computer remained at the Materials Laboratory, and the students remained in the classroom. During the first pilot test, teams of four students each ran tests in succession using a single client computer, as shown in Figure 2. The Virtual

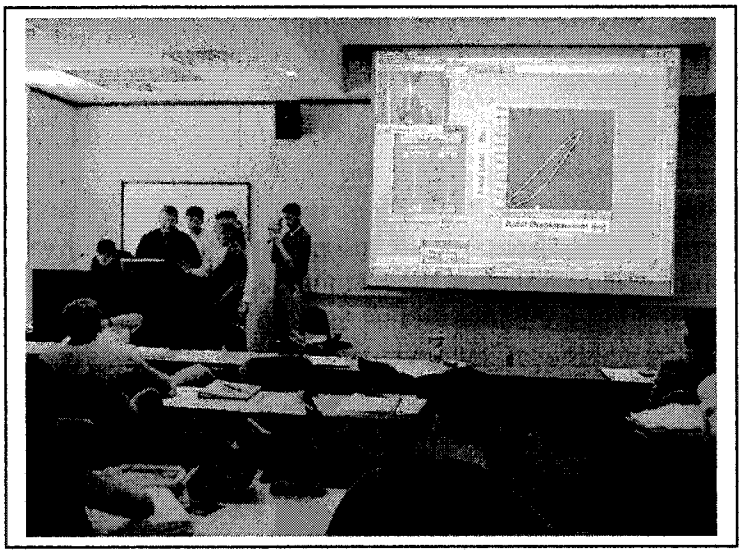


Figure 2. A team of students performing a remote tension test

Instrument (VI) example used was designed to be repeated immediately after a run. This was achieved by specifying a single-cycle loading history for a run. The specimen was simply attached once by an operator at the Materials Lab and the specimen was loaded cyclically as many times as needed. The student operator selected the *maximum angular displacement* of the crosshead and also the *rotational speed* for a torsion test. After setting these two parameters, the VI was executed remotely from the client computer at the classroom. The data points were plotted on the screen concurrently with the motion of the servomotors. In addition to the control panel of the VI, the student operators were able to see a video of the current experimental setup to obtain a feedback of what is currently happening physically at the Materials Laboratory. For the video feedback *NetMeeting* from Microsoft was used. At the end of the cycle, the data points were stored for the students.

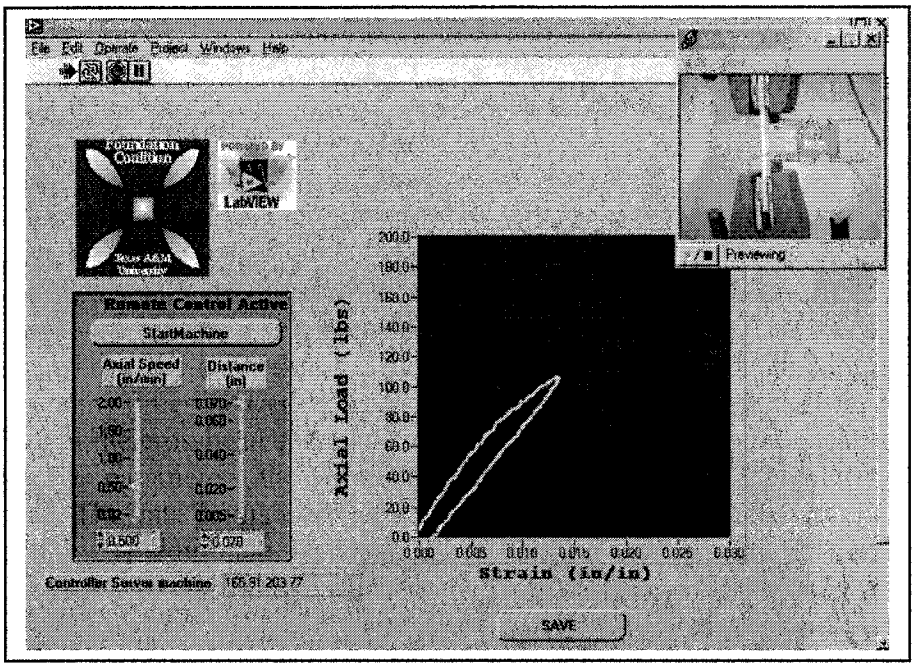


Figure 3. Control panel in LabVIEW used for the remote tension tests.

Example

Data collected using a solid Al cylinder is shown in Table 1. The left-hand two columns represent the data collected during the experiment, while the remaining columns are data calculated from the first two columns. A plot of all stress-strain data is shown in Figure 4. If only the elastic portion is considered, Figure 5 illustrates this portion of the data. The shear modulus determined from the above data for a solid cylinder of Al is 2×10^6 psi, which compares with 3.6×10^6 as given in Callister's book (Material Science and Engineering An Introduction, 4th ed. pg. 114). The lower value may be attributable to the fact that a solid cylinder was tested rather than a thin walled cylinder.

Table 1. Data collected and analyzed for an Al cylinder.

Torsion Experiment				Shear	Shear
Revolution	Torque	Radians	Torque	Strain	Stress
	in-lb		in-lb	in/in	psi
0	-13.0466	0	-13.0466	0	-4254.69
0.0008	-10.9876	0.005027	-10.9876	0.000209	-3583.22
0.0015	-8.7243	0.009425	-8.7243	0.000393	-2845.12
0.0024	-6.6148	0.01508	-6.6148	0.000628	-2157.18
0.0031	-5.0698	0.019478	-5.0698	0.000812	-1653.34
0.004	-3.6331	0.025133	-3.6331	0.001047	-1184.81
0.0048	-2.8748	0.030159	-2.8748	0.001257	-937.514
0.0056	-1.5293	0.035186	-1.5293	0.001466	-498.727
0.0064	-0.1554	0.040212	-0.1554	0.001676	-50.6782
0.0072	1.2603	0.045239	1.2603	0.001885	411.0023
0.008	2.8319	0.050266	2.8319	0.002094	923.5241
0.0088	4.4034	0.055292	4.4034	0.002304	1436.013
0.0095	5.9086	0.05969	5.9086	0.002487	1926.881
0.0104	7.1869	0.065345	7.1869	0.002723	2343.753
0.0112	8.4873	0.070372	8.4873	0.002932	2767.833

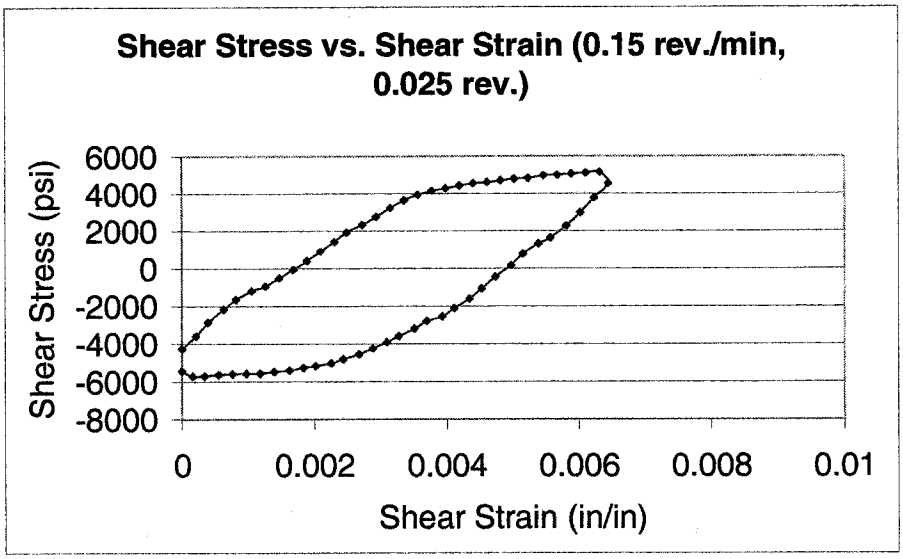


Figure 4. Plot of the shear stress vs. the shear strain for the data shown in Table 1.

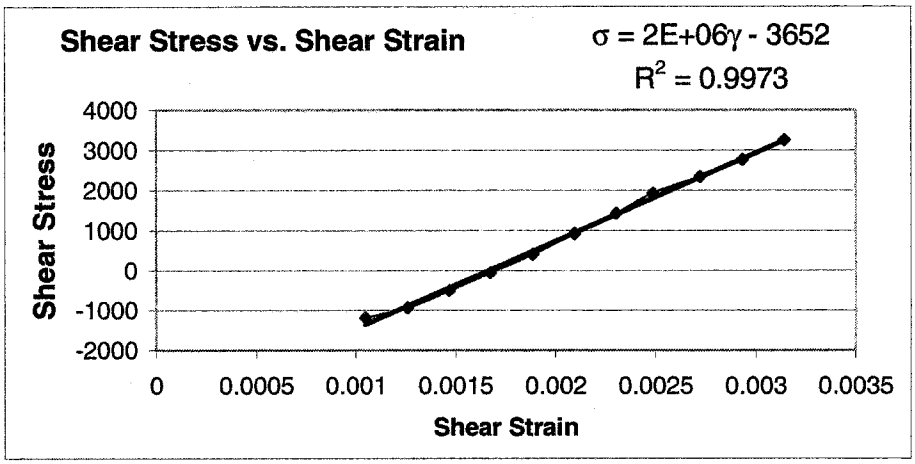


Figure 5. Elastic portion of the shear stress vs. shear strain data.

Using this setup, students did not need to worry about the technical details of setting up the experiment but rather just focus on the underlying physics of the problem and the interpretation of the results. The students were already familiar with the experimental setup since they had weeks before visited the laboratory performed a tensile test. The class was able to complete testing in a less than half the time it required with sending student groups to the laboratory. Efficiency can be further increased by using existing classrooms where every two students can share a laptop. This arrangement will be managed in the future using the various client/server features of DataSocket. The technical support received from National Instruments for the implementation of DataSocket was extremely helpful during the development of this test. The successful delivery of the first pilot test was possible as a result of the combined efforts from the Foundation Coalition Team at Texas A&M University and National Instruments.

Acknowledgements:

The authors would like to thank the National Science Foundation for their support through the Foundation Coalition, Director Karen Friar, University of Alabama. Project No. NSF EEC-9221460.

References:

[1] Malave, C.,"Teaming in the Integrated Curriculum of the Foundation Coalition at Texas A&M," ASEE National Conference, Washington, D.C., June 1996.

[2] Griffin, R. B., Everett, L. J., Keating, P., Lagoudas, D., Tebeaux, E., Parker, D., Bassichis, W. and Barrow, D., "Planning the Texas A&M University College of Engineering Sophomore Year Integrated Curriculum," Fourth World Conference on Engineering Education, Oct. 95, St Paul, MN, vol. 1 pp. 228-232.

[3] Yapura, C. L., Griffin, R. B., Lagoudas, D. C., "Mechanics of Materials Experiments Via the Internet," NIWeek 99 Conference Proceedings, Austin, TX, Aug. 1999.

LECTURE WORK NOTES FOR INTRODUCTORY MATERIALS ENGINEERING CLASSES

Stephen Krause

Department of Chemical and Materials Engineering
Arizona State University
Tempe, Arizona 85287-6006

Telephone: 480-965-2050
e-mail skrause@asu.edu

Stephen Krause

Lecture Work Notes for Introductory Materials Engineering Classes

Stephen Krause
Department of Chemical and Materials Engineering
Arizona State University
Tempe, AZ 85282

Abstract

This paper describes a method for delivering technical subject matter by a method referred to as "lecture work notes". It is a method that is a variation on traditional blackboard lectures but enhances student involvement and participation in the lecture. The "lecture work notes" method essentially consists of a framework of complete handout-based lectures in which critical components of the lecture content are left as open spaces. These are then filled out during the lecture by individual students who participate in the development of the instructor's overhead lecture writings. This approach allows more time and attention to be devoted to the "active analytical content" of the lecture rather than the "passive descriptive content" of the lecture. Students are very positive about the use of the method and it appears that student performance in understanding material can be enhanced

Key Words: Lecture work notes, teaching methodology, student interaction

Introduction

A wide variety of approaches are used today to communicate subject matter in materials engineering and other technical courses. Although the majority of classes taught in the Materials Engineering Program at Arizona State University rely upon the traditional blackboard lecture method, this approach is being supplemented by methods which increase the involvement of students during the class lecture. These methods, which are not unique and are being used to varying extents at other institutions, include classroom demonstrations, individual student exercises and experiments, and team-based exercises, experiments, and projects. One variation of these methods that can be used is "lecture work notes", which is the subject of this paper.

The Lecture Work Note Method

The "lecture work note" method is a relatively straightforward evolution of my teaching technique. My approach to teaching has shifted from textbook-based blackboard lectures, to textbook-based blackboard lectures supplemented by handout notes, to textbook-referenced "lecture work notes". These notes essentially consist of a

skeleton of complete handout-based lectures in which critical components of the lecture content are left as open spaces. These spaces are then filled out during the course of the lecture by individual students as they participate in the development of the instructor's overhead lecture writings. So the form of the notes might include the framework of a diagram, but with the contents of the diagram being filled in during class from overhead projector generated by a dialogue between the instructor and students. This approach allows more time and attention to be devoted to the "active analytical content" of the lecture rather than the "passive descriptive content" of the lecture. I find that this method is particularly useful for class sizes beyond 30 to 40 students, since students are more involved in the lectures and the time savings creates the possibility of more student interaction. Developing subject matter in computer format also allows easy sharing and modification of content by other instructors teaching similar content

An example of this approach is in the teaching of Miller indices. In the "lecture work notes" the orthogonal XYZ axes are shown with a unit cell cube inscribed upon them. In one set of exercises six or eight examples of conversion of a set of Miller indices to a given plane in a unit cell are worked through with input from the students. The next topic is, conversely of course, working through a set of exercises of determining Miller indices from planes as represented in unit cell diagrams. Although using this approach may seem to be a somewhat trivial variation on the usual blackboard lecture, it actually proves to be a good tool for facilitating and communicating the concepts. Some benefits with respect to this type of exercise are; significant amount of time conserved from not drawing the axes and unit cells or the planes in unit cells; improved accuracy of the drawings by the instructor; and improved accuracy of the drawing student. An example of a blank sheet and a filled-in sheet of "lecture work notes" from the Miller indices topic are shown at the end of this paper.

The "lecture work note" method proves to be especially valuable in lectures on subject matter which relies heavily on complicated figures or equations. This is particularly true for topics such as crystal structures, phase diagrams, and microstructures. In the presentation of equations that describe the physical processes represented by the parameter symbols, names and units is included in the notes while an equation itself and the functional relationships of the physical parameters (directly proportional, inversely proportional, exponential, etc.) are then presented in lecture. This approach allows time to engage student input into the development of an equation and relationships. The dialog, questioning, and postulating with students improves their focus and understanding. In the student evaluation of the "lecture work notes" one frequent comment was, which I did not anticipate, that the natural organization of the notes was a valuable tool in studying subject matter for quizzes and tests because students could easily compare their notes a particular page from the standardized "lecture work notes".

Students also commented that they have more time to listen, think, and participate without having to copy blackboard notes at a frenetic pace

The physical body of the "lecture work notes" is not excessive, requiring typically four to eight pages per lecture for 20 lectures. This consumes about 100 to 150 pages of material for a given course. I find that a significant amount of open space adjacent to figures, diagrams, and equations is useful so that students have an opportunity to record thoughts, comments and dialog on the notes. The "lecture work notes" prove to be particularly valuable for diagram-intensive courses such as Materials Characterization Techniques. When discussing instrumentation components for techniques, such as Auger spectroscopy, scanning electron microscopy, etc., the use of diagrams in the particularly useful for students. The drawback with these figures, of course, is that copyright permission must be obtained from publishers if they are taken from text books. If drawn by computer by the instructor, or by a teaching assistant, they are time consuming and/or expensive. Another valuable resource for figures is from sites on the internet, although copyright permission would probably have also be obtained from the source. I mention this since I have noticed that some of the clearest and most descriptive diagrams that I have ever seen in students' term papers have been directly downloaded from the internet.

Short assessments of the use of "lecture work notes" in comparison with the blackboard lecture method in three or four classes were conducted. The results are generally quite positive with the finding that more than 75% "prefer" or "strongly prefer" the "lecture work notes". The impact on student learning is less certain. In examining the final grades for introductory classes of 50 students in Structure and Properties of Materials there were shifts in the distribution. Roughly speaking, there was a shift upwards of a moderate fraction of B grades to A grades (which increased by about 50%), while the fraction of C grades was roughly unaffected. One interpretation of these results is that the "lecture work notes" did not help the less motivated students in the C range, but they did help improve some of the more motivated students in the B range.

Summary and Conclusions

A brief summary of the advantages and disadvantages of the "lecture work notes" method of teaching materials engineering courses is summarized below. The advantages of the "lecture work notes" technique include":

* improved legibility of instructor handwriting and figures
* decreased student and instructor writing fatigue
* increased participation of students in class
* increased attention of students during filling in notes
* increases student involvement and opportunities for interaction in large classes
* increased highlighting of important content and concepts

* computerized class content and subject matter is easily shared and modified by other instructors teaching the same or similar course content
* significant savings of class time with reduced writing and figure drawing
* student thinking, questioning, and dialogue increases with time savings

Some disadvantages of the "lecture work notes" technique include":
* students can have more time to daydream by rote copying of overhead material
* "work notes" can be copied and distributed to students not attending class
* modification and development of "lecture work notes" is time consuming
* obtaining copyright permission or redrawing of figures is time consuming
* moderate amount of paper is consumed with figures and blank spaces in "lecture work notes"

Overall, the "lecture work notes" technique has proven to be a useful method to communicate subject matter in materials engineering which improves student participation in lectures and enhances student learning. It has the flexibility to be adapted by instructors with varying content in lecture notes while a computerized format allows easy sharing and modification of content by other instructors teaching courses with similar content.

PLANES IN UNIT CELLS

Miller Indices - give the orientation of a given plane. They are enclosed in "rounded brackets ( ) and are denoted by the integer indices (h k l). They represent the reciprocals of the intercepts of a plane at the unit cell axes. Negative indices are denoted by a bar above the index number.

Examples - (1 1 2)
(1 2 1)
(0 1 0)
(1 1 0) BCC close packed plane
(1 1 1) FCC close packed plane

Mistakes - [1 1 2] _____
1 2 1 _____
(-1 1 0) _____
(1, 1, 0) _____
(2 4 6) _____

DRAWING THE PLANE FROM MILLER INDICES - A RECIPE

1) Choose origin in unit cell
2) Invert indices
3) Locate & mark intercepts (go back to origin after marking each intecept)
4) Connect intercepts

Example -

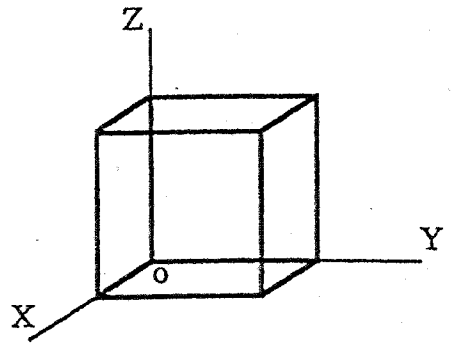
(1 1 1)

1)

2)

3)

4)



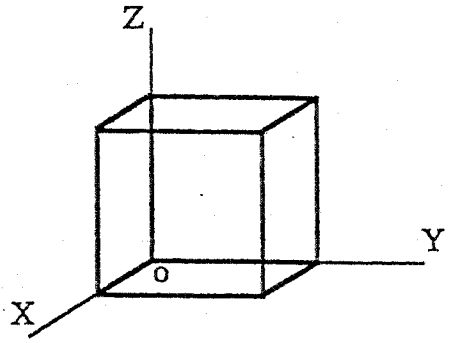
(1 1 0)

1)

2)

3)

4)



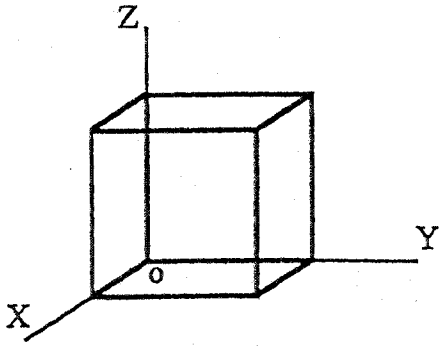
(1 0 0)

1)

2)

3)

4)



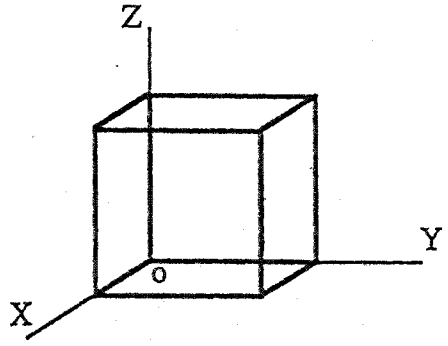
(0 1 2)*

1)

2)

3)

4)



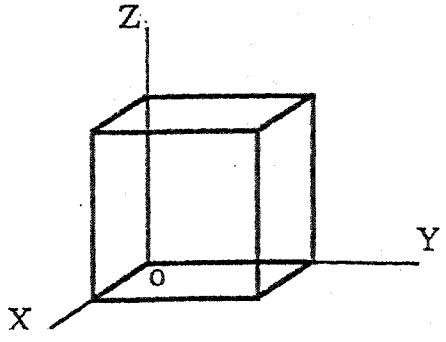
(1 1 0)

1)

2)

3)

4)



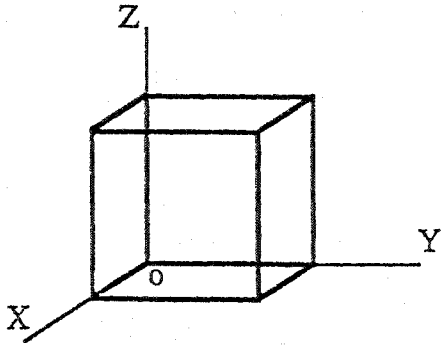
(0 0 1)

1)

2)

3)

4)



[ ] ~ direction < > ~ family of directions { } ~ family of planes

PLANES IN UNIT CELLS

Miller Indices - give the orientation of a given plane. They are enclosed in "rounded brackets ( ) and are denoted by the integer indices (h k l). They represent the reciprocals of the intercepts of a plane at the unit cell axes. Negative indices are denoted by a bar above the index number.

Examples - (1 1 2)
(1 2 1)
(0 1 0)
(1 1 0) BCC close packed plane
(1 1 1) FCC close packed plane

Mistakes - [1 1 2] Wrong brackets
1 2 1 no brackets
(-1 1 0) T10 ∅
(1, 1, 0) comma ∅
(2 4 6) (1 2 3)

directions - addition
planes - reciprocal intercepts

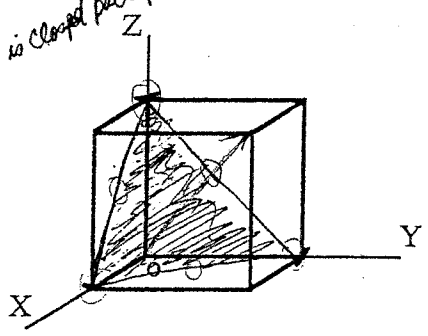
DRAWING THE PLANE FROM MILLER INDICES - A RECIPE

1) Choose origin in unit cell
2) Invert indices
3) Locate & mark intercepts (go back to origin after marking each intecept)
4) Connect intercepts

Example -

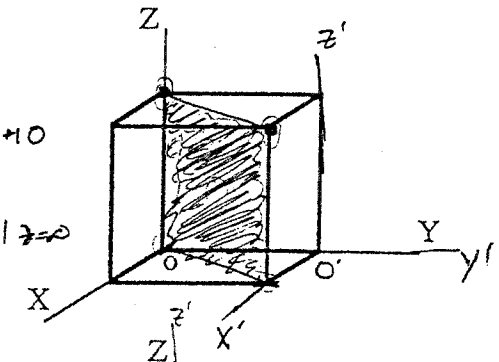
(1 1 1) in FCC is closed pack plane

1) origin 000
2) $\frac{1}{1}\ \frac{1}{1}\ \frac{1}{1}$
3) x = 1, y = 1, z = 1
4)



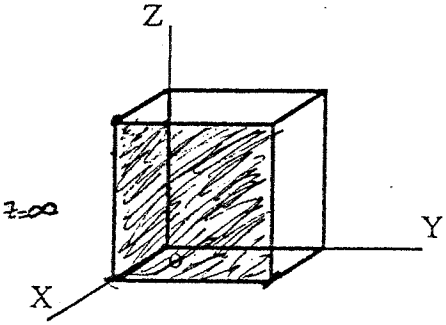
(1 $\bar{1}$ 0)

1) origin O' = 0 1 0
2) $\frac{1}{1}\ \frac{1}{1}\ \frac{1}{0}$
3) x = 1 y = 1 z = ∞
4)



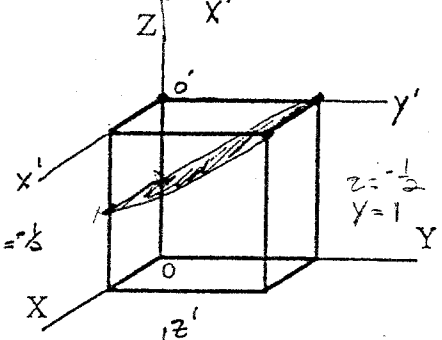
(1 0 0)

1) origin 000
2) $\frac{1}{1}\ \frac{1}{0}\ \frac{1}{0}$
3) x = 1 y = ∞ z = ∞
4)



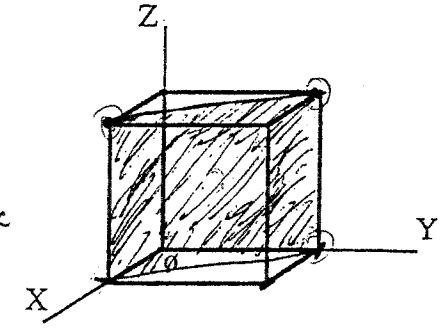
(0 1 $\bar{2}$)

1) O' = 0 0 1
2) $\frac{1}{0}\ \frac{1}{1}\ \frac{1}{-\frac{1}{2}}$
3) x = ∞ y = 1 z = $-\frac{1}{2}$
4)



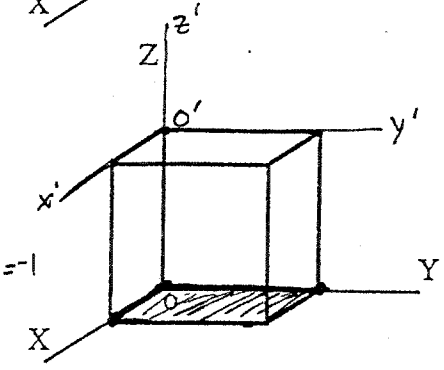
(1 1 0)

1) origin 0 0 0
2) $\frac{1}{1}\ \frac{1}{1}\ \frac{1}{0}$
3) x = 1 y = 1 z = ∞
4)



(0 0 $\bar{1}$)

1) O' = 0 0 1
2) $\frac{1}{0}\ \frac{1}{0}\ \frac{1}{-1}$
3) x, y = ∞ z = -1
4)

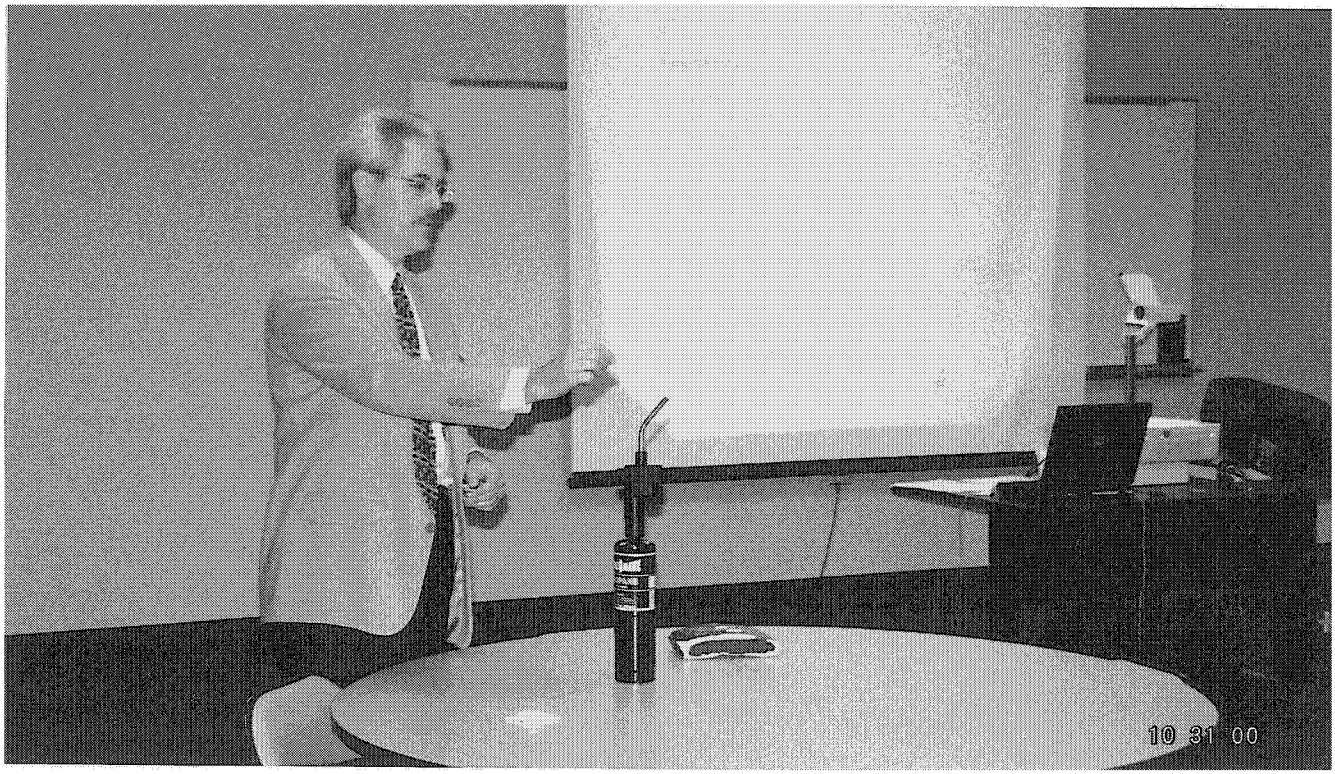


A DECADE OF CERAMICS OUTREACH

Mark Glasper

Director of Communications
The American Ceramic Society
P. O. Box 6136
Westerville, Ohio 43086-6136

Telephone 614-794-5898
e-mail mglasper@acers.org



Mark Glaspher

A DECADE OF CERAMICS OUTREACH

The American Ceramic Society initiated an outreach program ten years ago with a focus on precollege education. Over the years various support materials have been developed, including brochures, periodic tables, bookmark sets, videos and ceramic sample kits. Individual members, selections and student branches were invited to participate in the program. Currently, members around the world are sharing their time and the Society's materials with students to raise their awareness of ceramics.

The highlight of the ACerS outreach effort has been the recent two-and-a-half-year tour of the traveling exhibit, "The Magic of Ceramics". The ten-case exhibit traveled more than 7500 miles to eleven different cities nationwide. More than 250,000 people have seen the exhibit in its venues which have mostly been science and technology museums. The exhibit now resides permanently in the Ross C. Purdy Museum of Ceramics, sponsored by Saint-Gobain, at ACerS headquarters in Westerville, Ohio.

Even more recently, ACerS has published two books that further outreach efforts. "The Magic of Ceramics", by David Richerson, and "Boing-Boing the Bionic Cat", by Larry Hench, are excellent examples of what can be done to raise ceramics awareness and its engineering discipline.

Examples from the outreach program, including experiments, will be highlighted.

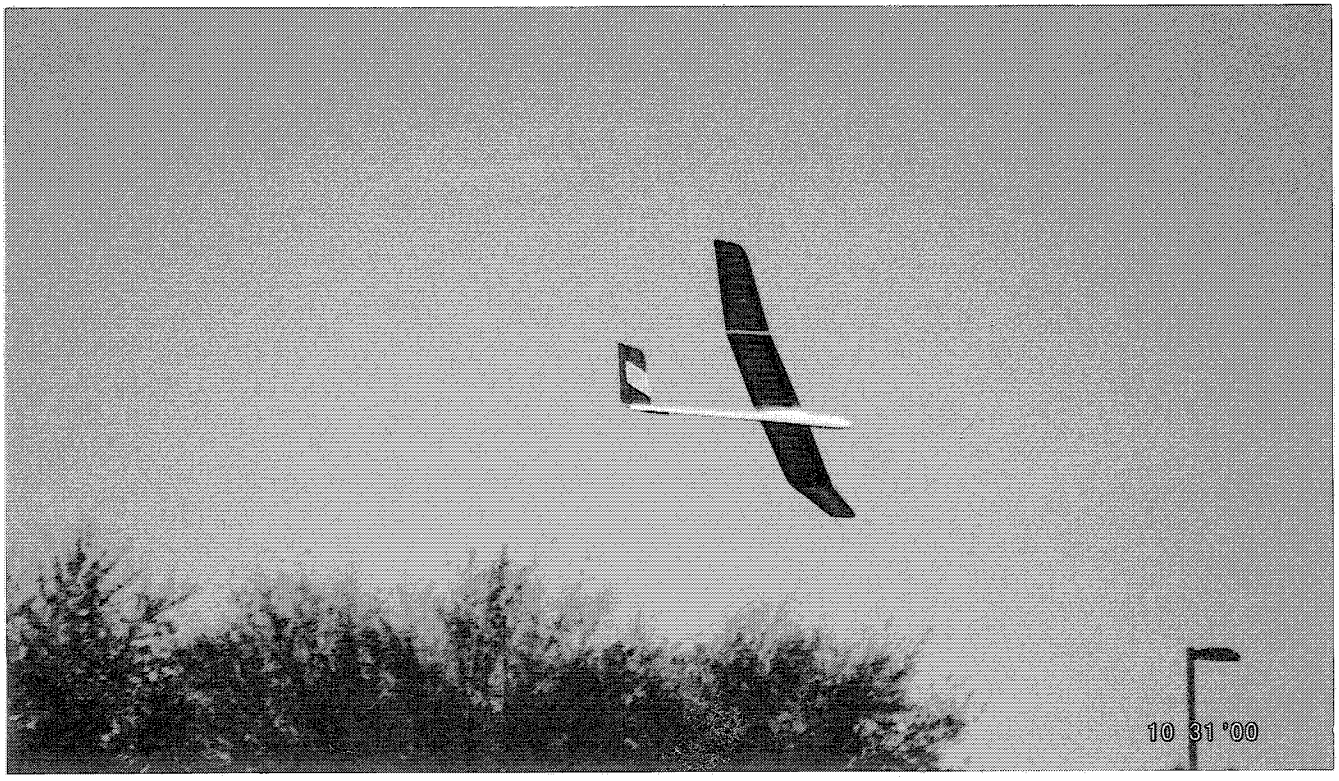
MODERN MODEL AIRPLANES AS FLYING COMPOSITES

L. Roy Bunnell

Southridge High School
Kennewick, WA 99338

Telephone 509-734-3800
e-mail bunnro@ksd.org

L. Roy Bunnell



MODERN MODEL AIRPLANES AS FLYING COMPOSITES

L. Roy Bunnell
Southridge High School
Kennewick, WA 99336

Key Words: Composites, Model Airplanes, Balsa, Radio-Controlled Airplanes

Prerequisite Knowledge: Students should have some instruction in elements of aerodynamics, including lift, drag and stability, as well as basic composite concepts such as stressed-skin reinforcement. The concepts in this paper are transferable to various academic levels, in that a type of model airplane can be chosen that is compatible with virtually any student population. The performance of any model chosen can then be enhanced by use of composite materials and construction, if it does not already include such. Since the materials are relatively delicate, students with some experience in model building will be far ahead of their peers in building skills. The instructor will have to adjust for this diversity, perhaps by having the more experienced act as peer coaches. (Students who are avid modelers may even be able to coach the instructor, to some extent)

Objective: To give students hands-on experience with weight-sensitive structures and provide a vehicle for composite concepts.

Equipment and Materials: Appropriate model kits, chosen from the list below, plus hobby knives, sandpaper, suitable adhesives and small amounts of glass cloth and graphite fabric, for reinforcement.
Gliders: Basic Balsa Glider, #7286, approx. $1/glider
Basic Rubber-Powered: Delta Dart, #9927, approx. $1.50/plane
More Advanced Rubber-Powered, #9925, approx. $3/plane
The kits and catalog numbers above are from Theta Technology Education, P. O. Box 70, Mound, MN 55364, one of many possible suppliers.

Introduction: Many in this audience probably had some early experience with model airplanes in their youth. In my own first experience during the 50's, model airplanes were built almost entirely of a light and strong wood, balsa. The structures were usually open frameworks to minimize weight, and models were consequently quite delicate. The framework was covered with light and stiff paper-based covering materials such as Silkspan, or special tissue papers that were then wet to shrink them tight. Shrinkage of the covering materials frequently created warps in the rather spindly structures, which had large effects on the model's flying ability. I doubt that I personally ever made a straight wing in those days.

In the many years that have passed since those days, the model airplane hobbyist has taken good advantage of new materials, combining them effectively with the balsa that has always been the main material of construction. Competition, even to the National level, has provided a driving force for continuous improvement in models. The modeler is driven by a need to produce structures of minimum weight but maximum

strength and stiffness, and to accomplish this now has access to materials such as those in the partial listing below:

Cyanoacrylate Adhesives, to provide adequate strength while adding only very small amounts of weight.

Fast-Curing Epoxies, to provide higher strength for high-stress areas of the structure, at some weight penalty.

Polyester (and other) Covering Materials, to provide a tough and light covering, shrink by application of heat but unlikely to warp structural framework, with a heat-activated adhesive and with as-supplied colors eliminating the need for heavy paint pigment. These covering materials are stiff and strong enough to function as stressed skins.

Very Light Glass Cloth (weight/area as little as 0.7 oz/sq. yd.), bonded to structures with epoxy for stressed-skin stiffening

Polystyrene Insulation, cut accurately to the airfoil shape with a hot, tightly stretched nichrome wire and used as the core for stressed-skin composite wings.

Graphite Fiber, available in several forms such as roving and fabrics of various weight/area, used for selective stiffening or wing reinforcement.

Procedure: After assessing the interests and craftsmanship of the group, choose an appropriate model type, from the following list:

Hand-launched gliders, generally all-balsa and with a wingspan <18 inches

Rubber-powered gliders, about the same size as hand-launched

Both of these model types are available as kits from various vendors, one of which is listed above. Assemble the kits, following instructions exactly. Cyanoacrylate adhesives and 5-minute epoxy will decrease building time. Previous to or during construction, point out to students that the the balsa wood in the kit has been chosen according to its density, since strength is proportional to density. As an exercise, students might be instructed to calculate the density of the different balsa supplied with the kit, correlating the density with the stress levels expected during launch and flight. For instance, horizontal and vertical stabilizers, if built of solid balsa, will be built from very low-density wood, while wing wood will have a higher density. Fiberglass cloth can be purchased that is extremely light, see list above. This cloth can be added to stress points in the airplane, attaching it with medium-curing (30 min) or slow-curing (3 h) epoxy. Of course, in weight-critical structures, the additional material added for the sake of strength must be minimized.

Once the models are constructed and carefully examined for straightness and soundness, they should be balanced as per kit instructions. Generally, modeling clay added to the nose of the planes provides an easily adjustable material for balancing. On a very calm day, planes can be taken outside and test-glided, and any final adjustments made. Finally, fly the planes in the manner intended, evaluating them by timing several flights and averaging, to find the best-flying planes in the class.

Comments: One of the most important features of this learning activity is that it is FUN. Though many of today's students have little or no experience with model airplanes, the

general concepts presented here are quite simple and students should be able to achieve impressive results if the model types are chosen appropriately. It would probably be best to start with a model type that the instructor considers too simple for the students, in order that they build successful planes. In subsequent years, the chosen model can be changed if necessary to align with student skill/experience. The model types chosen are admittedly simple, but could be used with students up to high-school age. The lack of experience of almost all of today's students will help to avoid feelings of déjà vu.

Demonstration: At NEW:2000, I will have a hand-launched radio-controlled glider, constructed so as to embody all of the concepts in the paper. This glider will be shown and, if outdoor space and weather permits, demonstrated.

References:

Ross, Don. Flying Models: Rubber, CO_2, Electric, & Micro Radio Control , Markowski International Publishers, 1998. ISBN 0-938716-54-9

MICROWAVE DIELECTRIC ANALYSIS OF SELECTED MATERIALS

J. N. Dahiya

Physics Department
Southeast Missouri State University
One University Plaza
MS 6600
Cape Girardeau, Missouri 63701

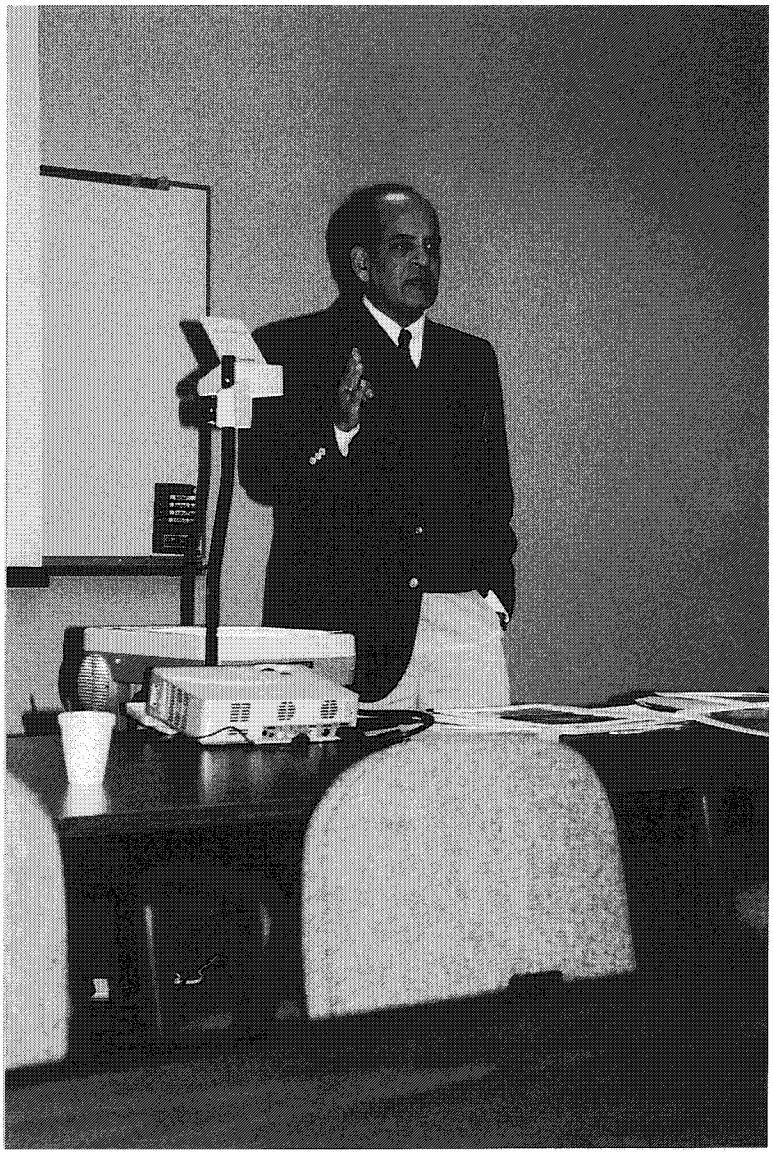
Telephone: 573-651-2390
e-mail dahiya@physics.semo.edu

and

J. A. Roberts

Physics Department
University of North Texas
Denton, Texas 76203

e-mail roberts@unt.edu



J. N. Dahiya

Microwave Dielectric Analysis of Selected Materials

J. N. Dahiya
Physics Department
Southeast Missouri State University
One University Plaza, MS 6000
Cape Girardeau, MO 63701
dahiya@physics.semo.edu

and

J.A. Roberts
Physics Department
University of North Texas
Denton, Texas 76203
roberts@unt.edu

Key Words

Polar molecules, dielectric relaxation, resonant cavity, perturbation of fields

Prerequisites

Knowledge of electromagnetic theory and basic components of electronics

Objectives

1. To understand the function of a microwave spectrometer for dielectric studies.
2. To understand the normalization procedure using Slater's equations.

Summary

Microwave dielectric response of trichloroethane and chlorobenzene is studied using a microwave spectrometer. The spectrometer is operated in the x-band of frequencies between 8.3 to 12.4 GHz using a Varian X-13 klystron. A cylindrical resonant cavity is used as a tool in the microwave spectrometer. The cavity is operated in the TE_{011} mode and the perturbations of the electric field inside the cavity is based on the Slater's equations. Using these equations and normalizing the fields, the real and imaginary components of the complex permittivity are determined at 10.1 GHz. The relaxation times for these materials are determined using Debye's equations.

Introduction:

The microwave spectrometer employed in this experiment has been used very extensively in dielectric studies of different materials [1-4]. The details of the spectrometer can be found in those references in which dielectric relaxation mechanism has been studied using a resonant cavity in T_{011} mode. The main purpose of using this mode is because of a very high Q-value for the resonant cavity. This makes the cavity very sensitive in terms of its perturbation of electric field. Similar techniques using resonant cavities in different modes have also been used [5-9]. A computer control system is used to monitor the temperature of the microwave resonant cavity very precisely.

Theory, Procedure, and Analysis:

Dielectric behavior of a material reveals very important information regarding the electrical nature of that material. It is measured in terms of the polarization capabilities of that particular material.

The dielectric constant of a polar liquid arises from the orientation of molecular permanent electric dipoles and the electrical distortion of the molecules. Both of these effects can be expressed in terms of a quantity P, the polarization, or dipole moment per unit volume of a continuous material:

$$P = (N_o / V)\bar{\mu}_o \tag{1}$$

where $\bar{\mu}_o$ is the average dipole moment per molecule, N_o is Avogardro's number, and V is the molar volume. The polarization process always involves rapidly forming polarization that consists mainly of electronic polarization, and may also involve slowly forming polarization.

Debye in his theory [10] explained the relaxation phenomenon and showed that the polarization of a dielectric medium in an electric field might arise from the partial orientation of permanent molecular dipoles by the field as well as from the distortion of electronic orbits in the molecules. The theory starts with an assumption about the time variation of the polarization in response to a step function removal of field. The simplest assumption is of an exponential decay

$$P(t) = P_o e^{-t/\tau} \tag{2}$$

where τ is the relaxation time. The physical meaning of such decay is that the rate of change of polarization is proportional to the difference between the instantaneous polarization and its final value. This relaxation assumption is often used in the theory of the return to equilibrium of a perturbed system.

Normalization of the fields in Slater's Equations:

A sample of material under study (trichloroethane and chlorobenzene) is placed into a capillary tube that in turn is attached to a micrometer drive. The presence of the sample causes the perturbation of the fields inside the cavity and as a result of that there is a frequency shift Δf and

Q-change of the resonant cavity. The frequency shifts and Q-changes are related to the real and imaginary parts of the complex dielectric constant through the perturbation equations [4]. Since the precise nature of the field in the cavity could not be ascertained relative values of ε' and ε'' are calculated for molecules in this investigation with respect to water as a standard. Constant parameters to be used in the Slater perturbation equations [4] are obtained for water. The changes in Δf and $\Delta\left(\frac{1}{Q}\right)$ as a function of mass of the sample residing in the cavity can be expressed by a simple power-law equation [11]. The data is fitted to equations of the form

$$\Delta f = A + B(\Delta m)^N \tag{3}$$

$$\Delta\left(\frac{1}{Q}\right) = A + B(\Delta m)^N \tag{4}$$

where A and C are the intercepts, B and D are the slopes, Δm is the fraction of sample mass advanced into the cavity and N is a constant which depends upon the geometry of the electro-magnetic fields inside the sample holder and the cavity. A computer analysis was made of the experimental data in order to determine what power of N led to a "best fit" for the data. The best value of N appeared to be 1.6. A plot of some of the data using N = 1.6 is shown in Figure 1.

Using equations (3) and (4) along with Slater's perturbation equations (5) and (6) given below

$$\frac{\Delta f}{f_o} = -\frac{\varepsilon' - 1}{2}\frac{\int \vec{E}_s \bullet \vec{E} dv}{\int \vec{E} \bullet \vec{E}_a dV} \tag{5}$$

$$\Delta\left(\frac{1}{Q}\right) = -\frac{\varepsilon' - 1}{2}\frac{\int \vec{E}_s \bullet \vec{E} dv}{\int \vec{E} \bullet \vec{E}_a dV} \tag{6}$$

one can write

$$\frac{\Delta f}{(\Delta m)} = B = f_o \frac{\varepsilon' - 1}{2} F(E) \tag{7}$$

and

$$\frac{\Delta \frac{1}{Q}}{(\Delta m)} = D\, f_o \varepsilon'' \quad F(E) \tag{8}$$

Where F(E) is given by

$$F(E) = \frac{\int_v \vec{E}_s \cdot \vec{E}\, dv}{\int_V \vec{E} \cdot \vec{E}_a\, dV} \tag{9}$$

And is a functional form of how the field interacts with the sample, E_a and E_s are the fields as applied to the cavity and the sample inside the cavity, E is the total field of the system, Δf is the frequency shift, and Q is the quality factor of the resonant cavity respectively, and f_o is the resonant frequency of the cavity.

All the samples are placed into small capillary tubes of constant diameter of 2mm to eliminate any geometrical effects. Now if F(E) is of the same form for all the samples, there arises a characteristic B_x and D_x for each sample of x. If B_w and D_w are the corresponding values for water one can express relative values for dielectric material as follows:

$$\frac{B_w}{B_x} = \frac{\varepsilon'_w - 1}{\varepsilon'_x - 1} \tag{10}$$

and

$$\frac{D_w}{D_x} = \frac{\varepsilon''_w}{\varepsilon''_x} \tag{11}$$

Equations (10) and (11) are used to calculate ε' and ε'' for trichloroethane and chlorobenzene using literature values of $\varepsilon' = 61.3$ and $\varepsilon'' = 29.7$ for water at 25°C at a frequency of 10.1 GHz.

A similar procedure is used to calculate the real and imaginary parts of the complex dielectric constant for these materials as a function of temperature. The thermal bath used in this experiment is very sensitive in terms of maintaining the temperature of the material when it is going through the phase change. A computer interface system is used to control the amount of air going through the thermal bath and in turn cooling the microwave resonant cavity to the desired temperature. The block diagram of such a system is shown in Fig. 2. The microwave dielectric response of trichloroethane and chlorobenzene as a function of temperature at 10.1 GHz is shown in Figs. 3-6. The microwave resonant cavity is very successful in studying the dielectric relaxation behavior of trichloroethane and chlorobenzene. The thermal bath used in this experiment is very sensitive and with this technique temperature can be varied by 0.1°C intervals.

References

1. Dahiya, J. N.: Dielectric Properties of Germanium and Silicon as Determined in the Microwave Field. *J. Mater. Educ.*, 13, 1991, p. 367.

2. Dahiya, J. N.: Dielectric Behavior of Superconductors at Microwave Frequencies. *NIST Special Publication 822*, 1990, p. 145.

3. Dahiya, J. N., and Freeman, R. W.: Computer Interfacing of a Microwave Resonant Cavity for Temperature Measurements During Dielectric Relaxation. *Computers in Physics*, Jul/Aug. 1989, p. 49.

4. Dahiya, J. N., Jani, S. K. and Roberts, J. A.: Phase Transition Studies in Polar and Non-Polar Liquids at Microwave Frequencies. *J. Chem. Phys.* 74(6), 1981, p. 3609.

5. Hong, K. H. and Roberts, J. A.: Microwave Properties of Liquids and Solids Using a Resonant Microwave Cavity as a Probe. *J. Appl. Phys.*, 45(6), 1974, p. 2452.

6. Arlt, G., Hennings, D., and de With, G.: Dielectric Properties of Fine-grained Barium Titanate Ceramics. *J. Appl. Phys.*, 58(4), 15 August 1985, p. 1619.

7. Gerson Robert: Dielectric Properties of Lead Titanate Zirconate Ceramics at Very Low Frequencies. *J. Appl. Phys*, 31(9), 1970, p. 1615.

8. Poirier, M., G. Quirion, K. R. Poeppelmeier and J. P. Thiel, "Microwave Study of the High-Tc Superconductors $La_{1.8}Sr_{0.2}CuO_4$," *Phys. Rev.* B 36(7): 3906(1987).

9. Lurio, A., and Stern, E. : "Measurements of the Dielectric Constant of BaTiO3 Single Crystals in the Paraelectric Region at x-band." J. Appl. Phys., 31, 1960, p. 1805.

10. Debye, P. : "Polar Molecules", Chemical Catalog, New York, 1929, Chapter 5.

11. Haniotis, Z. and Gunthard, H. H., Agnew, Z., Math. Phys., 20, 1969, p. 771

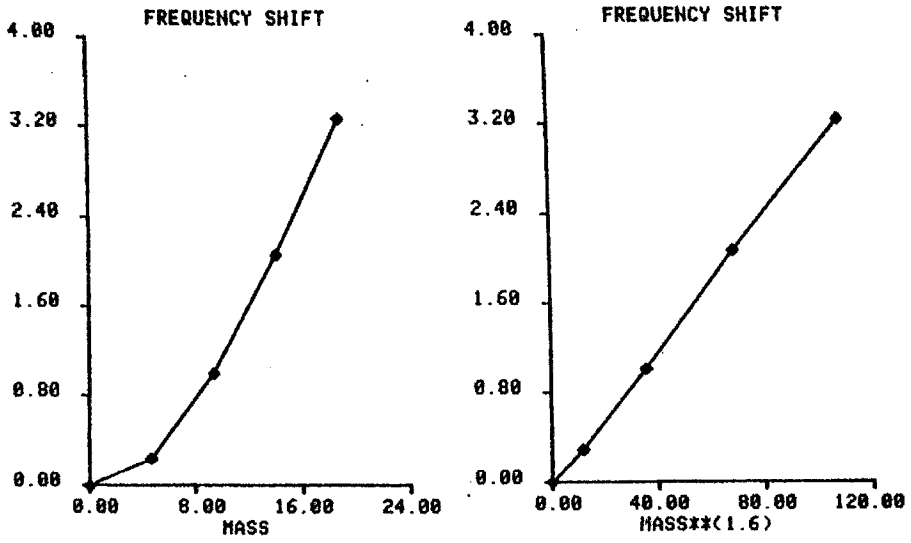


Figure 1. Frequency shift (MHz) as a function of mass (mg) and mass**(1.6) for water at a resonant
frequency of 10.1 GHz.

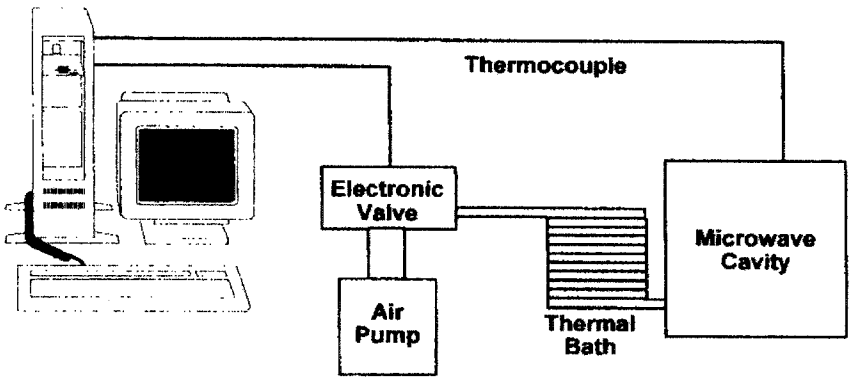


Figure 2. Experimental setup for dielectric studies showing the computer control system

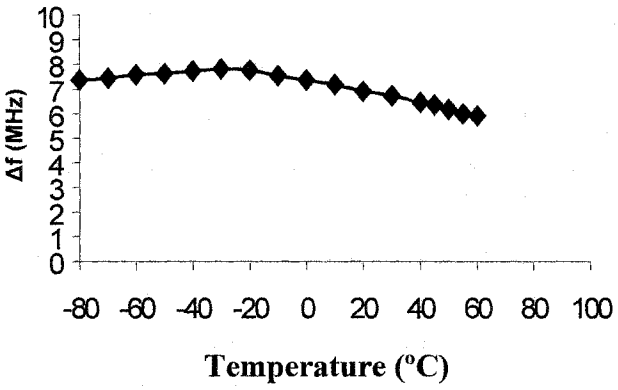


Figure 3. Frequency shifts of the resonant cavity as a function of temperature for a sample of trichloroethane at a microwave frequency of 10.1 Ghz.

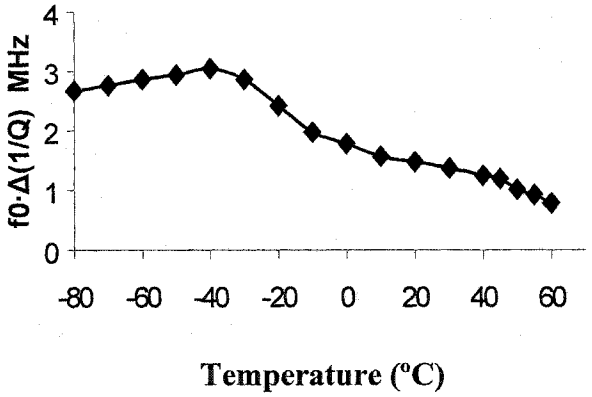


Figure 4. Changes in the Q-factor of the resonant cavity as a function of temperature for a sample of trichloroethane at a microwave frequency of 10.1 GHz.

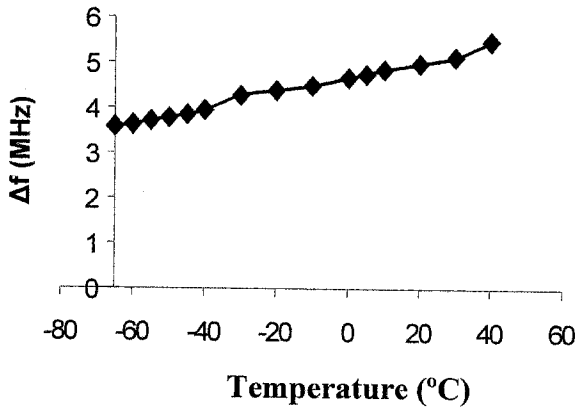


Figure 5. Frequency shifts of the resonant cavity as a function of temperature for a sample of chlorobenzene at a microwave frequency of 10.1 Ghz.

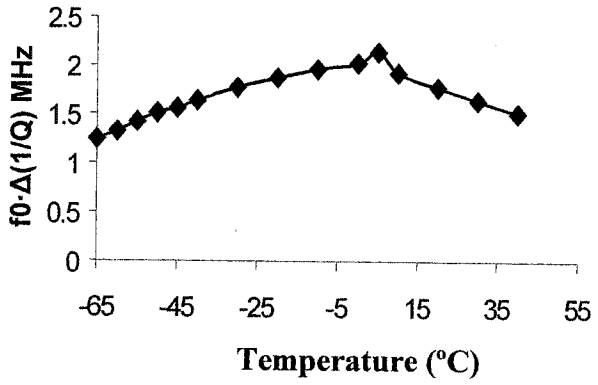


Figure 6. Changes in the Q-factor of the resonant cavity as a function of temperature for a sample of chlorobenzene at a microwave frequency of 10.1 Ghz.

LEARNING THE PRINCIPLES OF GLASS SCIENCE AND TECHNOLOGY FROM CANDY MAKING

Himanshu Jain

and

Isha H. Jain

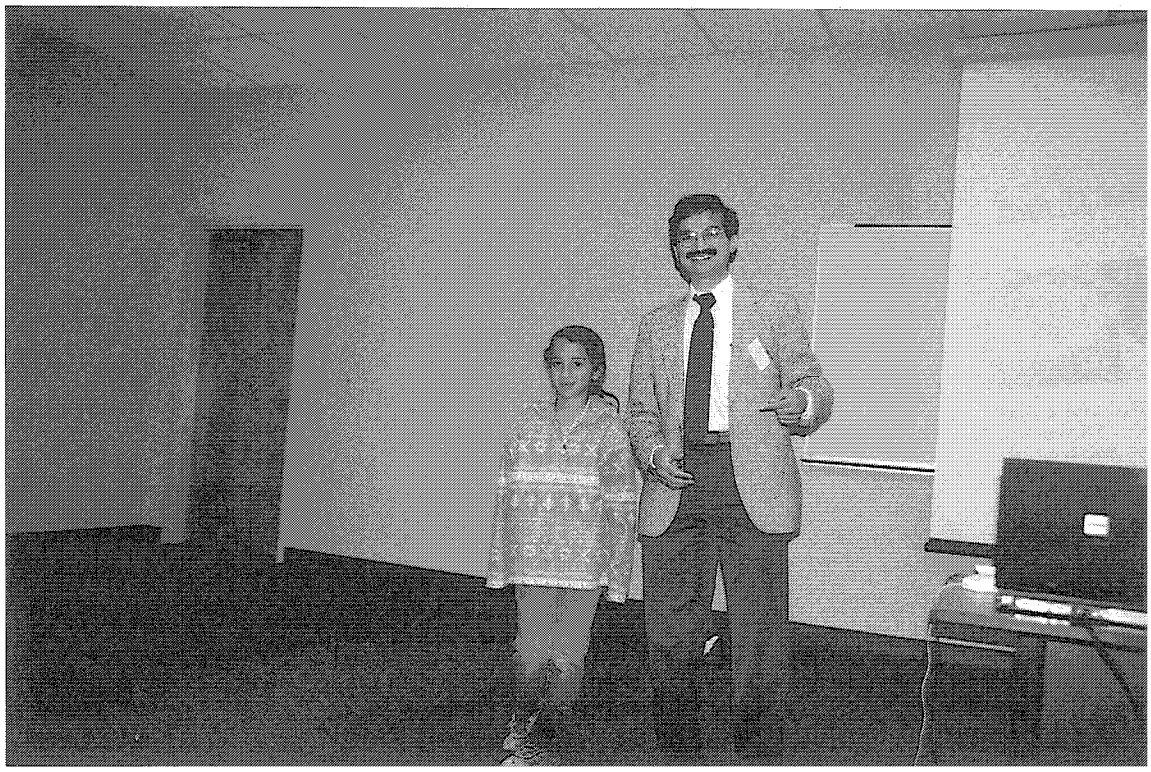
Department of Materials Science and Engineering
Lehigh University
5 East Packer Avenue
Bethlehem, Pennsylvania 18015-3195

Telephone: 610-758-4217
e-mail hj00@Lehigh.EDU

Biography:

Himanshu Jain is the T.L. Diamond Chair Professor of Materials Science and Engineering at Lehigh University. Earlier he was a researcher at Argonne and Brookhaven National Laboratories. He has developed both graduate and undergraduate courses in materials science, specializing in glasses and ceramics. He is a recipient of the Zachariasen award for outstanding contribution to glass research, Doan award by his Department's Senior class for the most influential teacher, a Fulbright Fellowship for lecturing and research at Cambridge and Aberdeen in UK, and a Humboldt Fellowship for research in Germany. He is a Fellow of the American Ceramic Society.

Isha Himani Jain is a fifth grade student at Governor Wolf Elementary School in Bethlehem, PA. A great enthusiast of math and science, she initiated the present work as her Science Fair project a year ago, and then completed the remaining experiments during past summer.



Learning the Principles of Glass Science and Technology from Candy Making

Himanshu Jain and Isha H. Jain
Department of Materials Science and Engineering
Lehigh University, Bethlehem, PA 18015

Key Words:
Glass formation, glass transition, nucleation, crystal growth, crystallization, viscosity, fiber drawing, glass-former, network-modifier, chemical durability, candy, hardness.

Prerequisite Knowledge:

The steps of candy making can demonstrate numerous principles of physical chemistry and materials science & engineering, which are typically taught from Middle School through College level. Notwithstanding, we discuss the experiment assuming that the student has completed High School level chemistry. Additional knowledge of the principles of binary phase diagram is desirable. The experiment is well suited for an Introductory course in Materials Science and Engineering, typically taken by most engineering majors. It will be also an excellent paradigm for a course on glass science or technology.

Objectives:

To observe and understand the following principles of glass science and technology:

1. When a homogeneous melt is cooled sufficiently slowly, one obtains a single crystal. Fast cooling yields polycrystalline solid. Glass is formed on increasing the cooling rate further, when crystal formation is fully suppressed.
2. Surfaces, insoluble impurities, mechanical agitation, bubbles, etc. in the melt can act as nucleating agents for crystal formation. These should be avoided if the goal is to obtain glass.
3. The addition of a modifier oxide to a glass-former oxide decreases the ability of the melt to form glass.
4. The glass-forming ability of a melt may be enhanced by increasing the number of components.
5. The addition of a modifier oxide generally deteriorates the chemical durability and mechanical properties of glass.
6. It is possible to draw glass fibers from melt but within a narrow range of viscosity, which in turn can be controlled by varying the temperature.

Equipment and Supplies:

1 one-quart stainless steel pan.
12 metal tablespoon
1 laboratory balance (or fluid measuring cup at home)
1 metal tray to hold hot candies (up to ~175 °C/ 350 °F)
1 laboratory or good quality candy thermometer that reads up to ~ 205 °C or 400 °F.
5 pounds of granulated cane sugar
16 oz.-bottle of corn syrup (e.g. Karo syrup available in supermarkets)
Drinking water

20 molds for casting the candies. The metal containers of *Tea Light* candles (small cookie cutters will also work well).
Four 8-oz. glasses.
Crystal candy, readily available as an aggregate of large clear, colorless crystals

Background:

Both the glass making and the candy making developed independently as empirical art in ancient times. Interestingly, the two technologies share same underlying principles, which can be learnt conveniently using kitchen tools. Common glasses such as the ones used in windows, tableware, bottles, etc. are based on silicon dioxide (SiO_2) (a.k.a. silica or common sand) as the main constituent.[1] Silica is one of the best *glass-formers*. It forms glass readily when cooled from the molten state. Among glass forming oxides it has one of the highest glass transition temperature (Tg)[2], strength, chemical durability, etc. In spite of its superior properties, however, pure silica (or quartz) glass is not used much due to its very high melting temperature (T_m), which makes cost of its manufacture prohibitively high. Commercial solution to this problem is to lower the melting temperature by adding alkali or alkaline earth oxides as flux (typically 13-18 wt% of Na_2O and 8-13 wt% (CaO+MgO)). These additives, which alone do not form glass easily, decrease the melting temperature by forming eutectics. They break the network connectivity of silica glass, and therefore, are known as network *modifiers*. In general, the addition of a modifier also deteriorates chemical durability, lowers Tg and decreases glass-forming ability of the glass. Therefore, a glass engineer must optimize the glass composition depending on the use and acceptable cost of the final product.

The candy making process serves as an excellent illustration of these principles of glass science and technology. Here sugar (i.e. sucrose, $C_{12}H_{22}O_{11}$ with T_m=186 °C) is a good glass former and water (H_2O with T_m=0 °C) a good modifier in a candy, just like SiO_2 (T_m=1723 °C) and Na_2O (T_m=1275 °C), respectively, are in a common glass.

Experimental Procedure:

Caution: The present experiments require working with high temperatures and hot liquids, which should be handled with appropriate insulation to avoid burning.

Note: The following recipe is suggested by the National Confectioners Association for making rock candy using sugar, corn syrup and water as the key ingredients. We break it down in three experiments by working with (a) sugar alone, (b) mixture of sugar and water, and finally (c) the mixture of all three ingredients.

Main steps of the suggested recipe:

- *Put 3.75 cups of granulated sugar (~820 g), 1.5 cups of Karo corn syrup (~480 g) and 1 cup of water (~200 g) into the saucepan, and heat gently until the sugar has dissolved, constantly stirring with the tablespoon.*
- *Bring to a boil and cook, without stirring, until the temperature reaches 310 F/154 °C.*
- *Remove from heat (and add candy flavoring and food coloring - not important for our experiment).*
- *Pour mixture onto a foil lined baking pan.*
- *Immediately remove foil from baking pan by sliding the pan out from under it.*
- *As mixture cools, cut with scissors*

[1] The broad scientific definition of glass is: It is a non-crystalline or amorphous solid. Common glass is but one sub-class of this wide range of solids that may include metals, polymers as well as ceramics.
[2] Roughly defined as the temperature below that the supercooled liquid behaves as a solid.

Experiment A. Formation of candy from pure sugar.

a. Take 410 g sugar in the pan and start heating gradually on hotplate or electric cook-top at Low-Medium temperature setting. Insert thermometer and monitor the temperature of sugar. Use the spoon to stir sugar, thus maintaining uniformity of temperature. Note: the thermometer bulb should be in the middle of sugar, and away from the bottom of the pan.
b. Continue heating and stirring until all the sugar has melted. The stirring speed should be such that solid and molten parts mix together. Note the temperature (T_m) when all the sugar has just melted, giving its melting point.
c. Stop stirring the melt. The temperature during this time should not be allowed to increase to avoid excessive browning of the melt and bubble formation, which occur from the decomposition of sugar.
d. Cast two candy samples (#A1 and #A2) by taking one and three, respectively, tablespoons of the molten sugar and pouring into two separate molds that were placed on the metal tray. Make a note of the physical appearance of the samples as they cool to room temperature (RT), especially about the transparency, presence of small white crystals and/or bubbles, and whether solid or liquid.
e. Turn the hotplate off. Attempt drawing fiber by slowly taking the spoon away from the syrup. Continue this process as the temperature of syrup decreases to solidification when fiber drawing becomes impossible. Make a note of fiber drawing ability as a function of decreasing temperature. Estimate the temperature (T_d) at which fiber drawing ability is maximum.
f. Compare the appearance of samples #A1 and #A2 with that of crystal candy that is also made of pure sugar.

Experiment B. Determine the effect of addition of water to sugar on the processing of candies.

a. Put 410 g sugar and 100 g water in the pan (these ingredients are in the same ratio as in the original recipe), and begin heating while stirring the melt. Monitor the increase of temperature as sugar dissolves. Note the temperature (T_s) at which all the sugar dissolves in solution.
b. Continue heating and stirring. Note the temperature (T_b) at which the syrup begins to boil. Cast candy from the syrup (sample #B1). Make a note of the physical appearance of the candy as it cools to room temperature, especially about the transparency, presence of small white crystals, whether solid or liquid, and relative viscosity at RT if it remains fluid.
c. Boil the remaining syrup, while also stirring, until the temperature increases by 5 °C i.e. it reaches $T_2=T_b+5$ °C. (A temperature increase of 10 °F may be used if working with a Fahrenheit thermometer, typically used in kitchen.) If solid sugar is deposited at the edges of the syrup, scrape and stir it into the liquid. Cast candy from this more concentrated syrup (sample #B2). Make a note of the physical appearance as before.
d. Continue repeating the previous step, casting a new candy for each 5 °C (or 10 °F) increment in temperature (sample #B3, #B4, ... etc.), until the temperature reaches ~170 °C (338 °F). Every time use a clean spoon to cast a new sample.

Experiment B(a). Determine the effect of stirring on the processing of candies made from sugar and water.

According to Objective #2, mechanical disturbances, the interface between the melt and surface of the pan, etc. can help nucleate the crystal formation. To verify this statement, repeat all the steps of Experiment B except that this time do not stir the solution after the sugar has settled at the bottom of the pan (at ~ 200 F). Try to cast the samples (#B1(a), #B2(a), #B3(a),... etc.) when the melt is at the same temperature as in Experiment B.

Record the changes in samples as they cool to room temperature, making special note of any differences compared to the corresponding B samples.

Experiment C. Determine the effect of addition of corn syrup to (sugar + water) mixture on the processing of candies.

This experiment is essentially a repetition of Experiment B(a), with the exception that now the ingredients also include 240 g corn syrup, in addition to 410 g sugar and 100 g water. To begin, place all the three ingredients in clean pan, follow all the steps of Experiment B(a), and note corresponding observations.

Experiment D. Effect of processing conditions on the properties of candies.

The experiments described below are designed so that little specialized equipment is needed. If appropriate equipment is available, such as for measuring hardness or viscosity, the students are encouraged to obtain quantitative data.

Hardness or Chewy character. The samples would have a wide range of hardness from brittle solid to a watery liquid. To make a comparison of this property, use a paper clip. Open the clip up from one end, providing one sharp end, and one bent end of the wire. Use the sharp end for testing solid samples by inserting the pin under approximately the same force. Compare the size of the dent thus created on different samples. For liquid samples, use the bent end of the pin. Dip it into the liquid and take it out, noting the relative force needed to do so.

Durability in water. Select one each of the A, B, B(a) and C samples (say the one cast from the melt at ~150 °C or 302 °F). Determine their weight (still in mold), using laboratory balance, and place them in separate 8-oz. glasses with 200 g tap water. (Note: all the water should be at the same temperature). Drain the water out after 1 h. Take the samples out, dry and weigh them again. This is a static experiment, so the sample and water should not be disturbed. Calculate the respective weight loss from dissolution in water. The loss of a sample's weight occurs from dissolution at the top surface that is exposed to water. Since the mold cross-section area is the same for all samples, the weight loss is inversely proportional to the durability. Therefore greater is a sample's weight loss, lower is its durability.

Some of the glassy or partly glassy samples may devitrify rather slowly. In that case, make a note of slow changes in the physical appearance of such samples over the next several days.

Record the qualitative information in the Table below by assigning relative grades 1 through 5, when possible. For example, in the Transparency column write 1 for an opaque and 5 for a completely transparent sample.

Example of Results:

Melting Temperature of sugar, T_m	= 344 °F
Temperature of maximum fiber drawing, T_d	= 190 °F
Temperature where the solubility of sugar in water is 410 g / 100 g, T_s	= 210 °F
Boiling temperature of the initial (sugar + water) syrup, T_b	= 220 °F

Temperature at which 410 g sugar dissolves in 100 g water + 120 g corn syrup, T_s' = 228 °F
Boiling temp. of the initial (sugar + water + corn syrup) solution, T_b' = 220 °F

Weight of as cast sample #A1 = 10.1 g
Weight of sample #A1 after dissolution in water = 9.1 g
Weight loss = 1.0 g

Weight of as cast sample #B5 = 22.7 g
Weight of as prepared sample #B5 after dissolution in water = 17.9 g
Weight loss = 4.8 g

Weight of as cast sample #B10(a) = 16.5 g
Weight of as prepared sample #B10(a) after dissolution in water = 15.1 g
Weight loss = 1.3 g

Weight of as cast sample #C10 = 19.8 g
Weight of as prepared sample #C10 after dissolution in water = 18.7 g
Weight loss = 1.1 g

Table of Observations

Sample # and time since casting	Casting Temp.	Transparency	Crystallinity	Relative Hardness (H) or Viscosity (V)	Comments
#A1		3.5	1.1	H: 5	Red-brown solid. Many bubbles. Sample used in durability test. (Fig. 1)
#A2		2	1.5 (?)	H: 5	Dark brown solid. Very large number of bubbles. (Fig. 1)
#B1	228	5→ 4→2.5	1→1.5	Cryst.+Liq.	
#B2	236	5→ 3→2.5	1→2	Cryst.+Liq.	Prior to casting, the hot syrup contained small white crystals (Fig. 2)
#B3	242	5→ 2	2→3	H:3 Cryst+Liq.	
#B4	256	5→ 1	2→4→4.5	H:4 Cryst+Liq.	
#B5		3→1	4→4.5	H:4.5 Polycrystal	
#B6		2→1	5→5	H:5.0 polycrystal	
#B1(a)	228	5→4.5→2.5	1→1→1.2→ 1.5	Cryst.+Liq.	Liquid fraction decreases as #B1(a)→ #B3(a)
#B2(a)	238	5→4.5→2.5	1→1.5→1.5	Cryst.+Liq.	
#B3(a)	248	5→2.0	1→2→2.5	V:4 Cryst.+Liq.	
#B4(a)	258	5→4→2.0	1→2.5	H:2	Bubbles form on pouring in mold.

Sample # and time since casting	Casting Temp.	Transparency	Crystallinity	Relative Hardness (H) or Viscosity (V)	Comments
				Non-sticky	Colorless liquid.
#B5(a)	268	5→2.0	1→3→3.5	H:3 Non-sticky	Many bubbles form on pouring in mold. Colorless liquid.
#B6(a)	274	5→2.0	1→2.5→3.5	H:2.5 Non-sticky	Many bubbles form on pouring in mold.
#B7(a)	288	5→2.0	1.5→2→3	H:3 Non-sticky	Light yellow liquid. Bubbles form on casting.
#B8(a)	298	5→1.0	1→2→3	H:3 Less sticky	Light yellow liquid. Bubbles form on casting.
#B9(a)	300	5→3.0→1.5	1→1.5→2.5 →2.5	H:3.5 More sticky	Yellow liquid. Shows crystal growth easily.
#B10(a)	310	4.5→4.5	1.5→1.5→2 →2	H:3.5 Sticky	Light brown liquid. Shows crystal growth easily.
#B11(a)	317	5→5.0	1→1.1→1.2	H:4	Brown liquid. Less bubble formation on casting.
#B12(a)	338	5→5.0	1→1	H:4.5	Dark brown liquid. Some bubbling.
#C1	228	5	1	V:2 Thick syrup	Can draw fiber at RT
#C2	238	5	1	V:3	
#C3	248	5	1	V:4	Wrinkling of surface later
#C4	258	5	1	H:1.5 V:4.5 Chewy	Crinkling of surface.
#C5	268	5	1	H:2.5 Sticky	Colorless. Surface crinkles after casting
#C6	278	5	1	H:3	Hue of yellow. Wrinkled next day.
#C7	288	5	1	H:3.5	
#C8	298	5	1	H:4	Pale yellow glass
#C9	300	5	1	H:4.5	Light yellow glass
#C10	310	5	1	H:4.5	Yellow glass.
#C11	320	5	1	H:4.5	Yellow glass
#C12	330	5	1	H:~5	Light brown glass
#C13	340	5	1	H:5	Brown glass

Brief Discussion:

Note: The following information is primarily for instructors. It is provided as an illustration of anticipated results and discussion of students' observations.

1. The melting temperature of pure sugar is observed to be 344 °F, which is lower than the value reported in literature, possibly because the present value was measured in a somewhat supercooled state.
2. The casting of pure molten sugar in a mold at RT gives a glass-like candy (A samples). It is light to dark brown, and translucent to opaque depending on the bubbles produced presumably from the decomposition of sugar (Fig. 1). The cast candy takes the shape of the

mold which contrasts with the faceted crystals of rock candy Therefore we infer that the cast candy is a non-crystalline or glassy solid

When crushed by a hammer the cast glassy candy behaves as hard and brittle as the crystalline rock candy suggesting that most likely there is no major difference between their mechanical properties

(In a separate experiment we grew sugar crystals from slow evaporation of saturated solution of sugar in water over a couple of weeks (Note Kits for this experiment are available from popular science stores) Many orders of magnitude longer time was available for sugar molecules in solution to organize in large crystals than the time of solidification of the cast Therefore we infer that shorter time for solid formation from disorganized liquid state promotes non-crystalline structure.)

3 From Experiment B we observed that at room temperature the (sucrose + water) mixture consisted of both liquid syrup and undissolved solid sugar On slow heating and stirring the solid phase disappeared at T_s=210 °F Therefore the solubility of sugar in water must be increasing with temperature Furthermore at 210 °F its value should be about 410 g per 100 g H_2O

4 On heating the solution after all the sugar has dissolved the single phase syrup begins to boil at T_b=220 °F On further heating the syrup continues to boil and at the same time the temperature also increases This can happen only if boiling causes a change in the syrup composition Since water has a much lower boiling temperature than sucrose we infer that boiling (at 220 °F) causes preferential loss of water from the syrup In turn, the syrup becomes increasingly viscous and concentrated with sucrose ultimately it would approach the 100% sugar composition In a way the boiling temperature becomes an indicator of the sugar content of the syrup Therefore the concentration of modifier oxide decreases in the sample order #B1(a) > #B2(a)> #B3(a)> #B4(a) etc Similar variation occurs among the C samples

5 The stirring of syrup induces crystal formation, thereby suppressing glass formation Once formed the crystals are difficult to dissolve back The crystalline solid preferentially formed at the thermometer and pan-syrup boundary A comparison of B and B(a) samples clearly shows that the samples cast from stirred syrup crystallize much more easily than the ones cast from unstirred solution (Fig 3) We were not able to obtain solid glass in B samples at RT either we obtained a mixture of crystal and liquid phases (#B1 – #B4) or a chunk of polycrystalline sugar solid (#B5 and #B6)

6 Within the B or B(a) series the appearance of most samples changed with time If the modifier content was high, the formation of polycrystalline chunks ensued after casting Figure 4 shows the crystal formation in B2 sample with increasing time With decreasing modifier content the crystal formation decreased gradually if the sample was not stirred Contrast Fig 5 vs Fig 4

7 At room temperature the glass forming ability increased with decreasing H_2O modifier content as shown by Fig 6 recorded about 12 hours after casting Here the samples B1(a) through B3(a) were a mixture of liquid syrup and polycrystalline solid sugar They did not form glass With decreasing water content the transparency of the samples decreased as the fraction of polycrystalline sugar increased However on further decrease of H_2O content the samples became increasingly more transparent Thus sample #B11(a) and #B12(a) remained completely transparent and glassy These observations confirm similar behavior of the SiO_2 Na_2O system.

8 The viscosity of the molten syrup (just before casting) increased as water boiled off gradually This occurred even as the temperature of observation i e the boiling temperature increased [3] Also at RT the viscosity of liquid samples increased with decreasing H2O content These observations are best exemplified by the experiment C for which glass formation was not a problem In this series the viscosity increased in the order #C1 < #C2 < < #C13 (see Table) Clearly the addition of modifier oxide decreases the viscosity of glass forming sucrose strongly The same statement is true for the SiO_2 Na_2O glass system.

9 The increase of RT viscosity with decreasing modifier content can be characterized as chewy to hard candy If a candy is chewy and clear it means that its glass transition temperature is below RT The less chewy is the candy much lower is its Tg than the room temperature Thus the Tg of sucrose water glass decreases with increasing modifier content The same is also true for the SiO_2 Na_2O glass system. In popular literature the hardness of a candy is said to depend on the temperature at which the syrup was boiled before casting Now we know that a more accurate cause of a candy s softness is the amount of water (the modifier) it contains!

10 For the glassy candy below Tg such as #C7 #C13 hardness increased with decreasing water content In other words the break up of network structure by a modifier decreases the hardness of a glass as is also true when Na_2O is added to SiO_2

11 As the melt temperature decreases the melt viscosity increases and the ability to draw sugar fibers (essentially making of cotton candy) increases (see Fig 7) However after a while the ability to draw fibers becomes increasingly difficult These observations show that viscosity of melt increases with decreasing temperature and only in a narrow range of viscosity (i e the temperature) it is possible to draw long fibers

12 Since the duration and surface area exposed to water were about the same for the samples of Experiment D the weight loss values indicate their susceptibility to attack by water The results show that pure sugar glass is most durable among the four samples Addition of H_2O modifier renders the glass more susceptible to the attack by water Some of this loss of chemical durability of the sugar glass is recovered when corn syrup is added Very much parallel technology is adopted for making common oxide glasses where the loss of durability of silica by the addition of Na_2O is regained by the addition of other oxides such as Al_2O_3

13 The polycrystalline sample #B5 showed much larger weight loss for two reasons (a) The sample was inherently less durable than the glassy form, especially at the grain boundaries (b) The sample was not a monolithic solid and was cracked Thus the surface area exposed to water was larger than for the other samples

14 Overall the observations of Experiment C confirm the various conclusions that are derived from Experiment B and B(a) In addition, we note that the viscosity of the liquid is increased by the addition of corn syrup The three components are soluble in each other The intimate mixing of sugar and corn syrup makes it difficult for sugar molecules to organize as crystals The tendency of sugar water glass to devitrify is strongly suppressed by the addition of corn syrup making it possible to obtain clear glassy candy at high modifier concentrations Without the addition of corn syrup it will be too difficult to obtain chewy clear candies from sugar water mixture alone

Acknowledgement The authors gratefully acknowledge the Diamond Chair endowment for supporting this work

[3] Contrary to this observation generally the viscosity of liquids decreases with increasing temperature

Bibliography:

1. Fundamentals of Inorganic Glasses, A.K. Varshneya, Academic Press, New York, 1994.
2. Chocolate Manufacturers Association / National Confectioners Association. http://www.candyusa.org

For color photographs in this paper, please refer to the web page at:
http://www.lehigh.edu/~inmatsci/jain.html

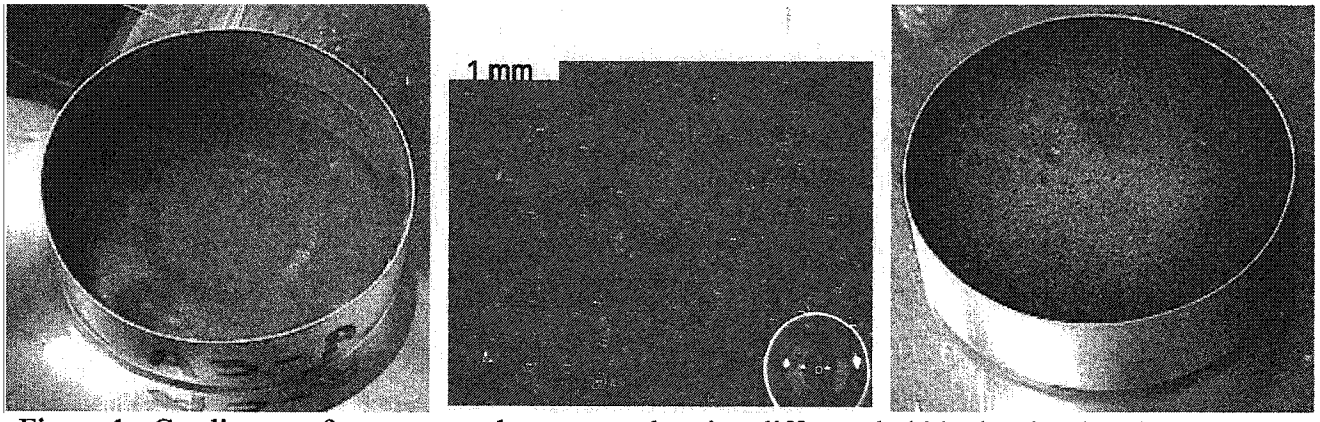


Figure 1. Candies cast from pure molten sugar, showing different bubble density that determines transparency. The figure in the middle is a magnified part of the one on the left. The right sample is thicker and opaque. It has a much higher bubble density.

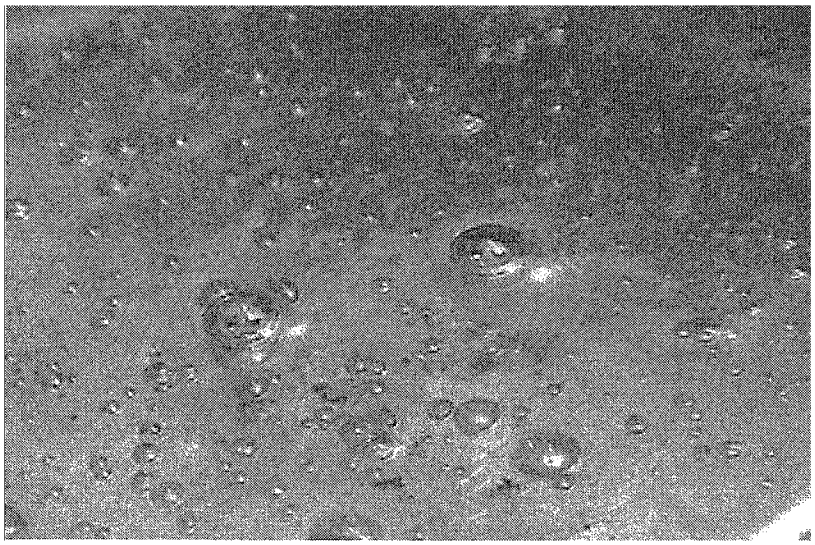


Fig.2. Small white crystals in the boiling liquid syrup, resulted from stirring action. These did not exist in the unstirred syrup. Scale: Figure diagonal = 14 cm.

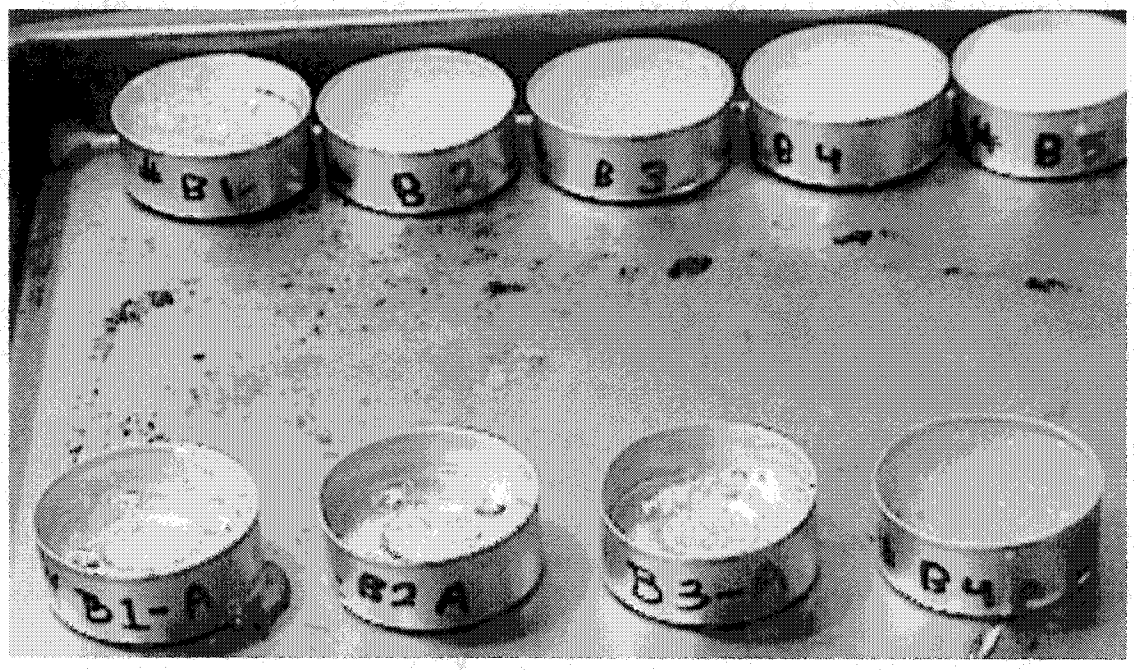


Fig. 3. The figure shows the effect of melt-stirring on glass formation. The samples in top row were stirred before casting, whereas the ones on bottom row were not stirred.

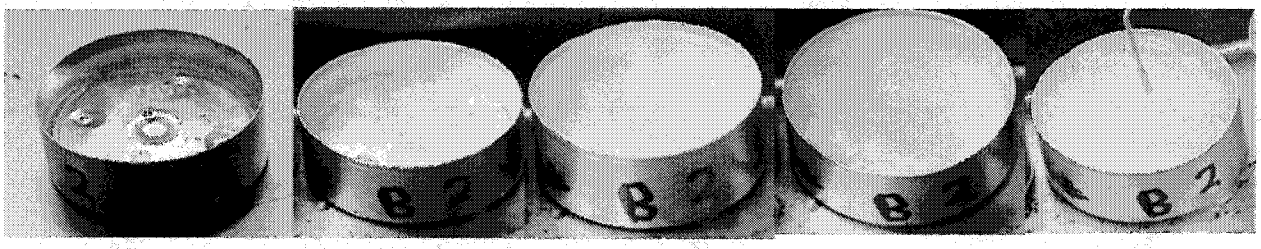


Fig. 4. Growth of sugar crystals in high modifier content mixture. The figure shows B2 sample with increasing time from left to right.

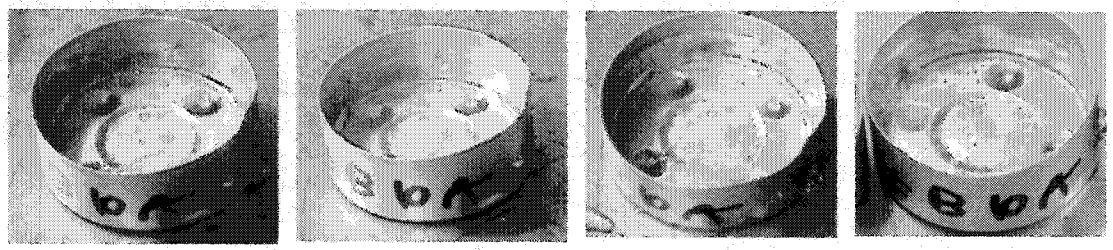


Fig. 5. Growth of sugar crystals in low modifier content mixture. The figure shows B10(a) sample with increasing time from left to right.

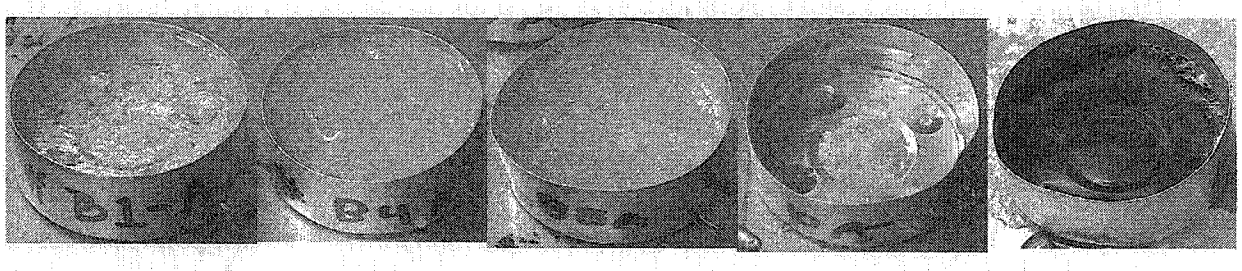


Fig. 6. Demonstration of increasing glass-forming ability with decreasing modifier content from left to right. Unstirred sugar+H_2O samples from Experiment B(a). Sample #B1(a) is mostly liquid with a few crystals floating. The fraction of crystals increases in #B4(a) and #B8(a), the latter being mostly solid. #10(a) is mostly solid glass with a few crystalline regions. Finally, the last sample (#B12(a)) is just solid glass.

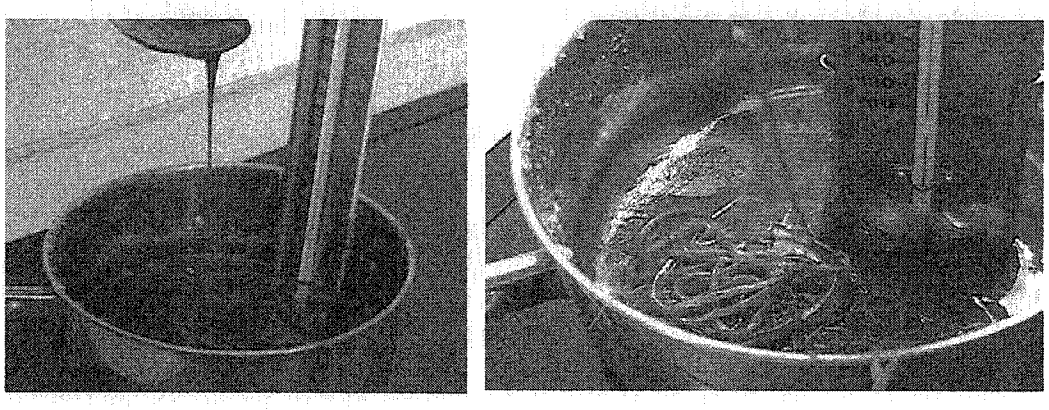


Fig. 7 Large changes in fiber drawing ability with a change in temperature just by a few F.

DETERMINATION OF VISCOSITY USING A FALLING SPHERE VISCOMETER

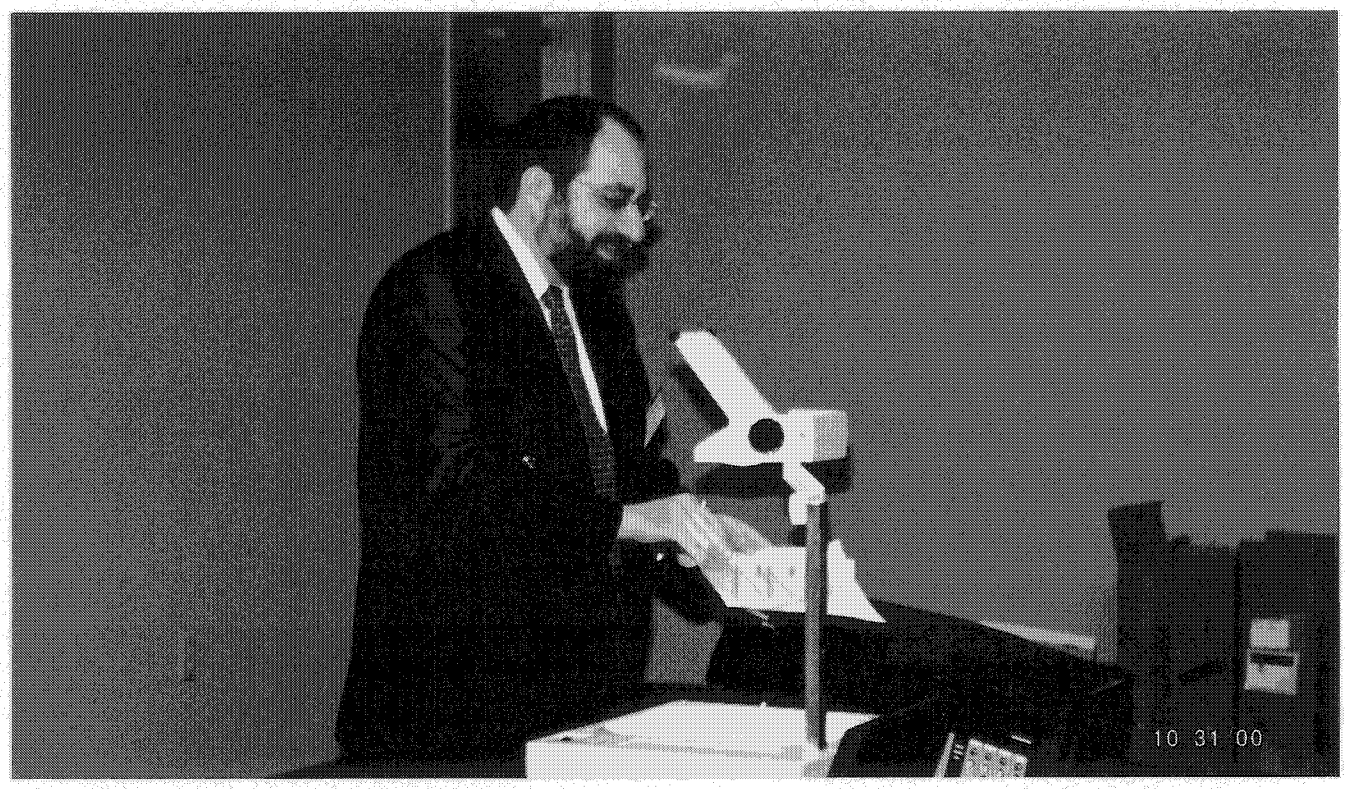
Harvey Abramowitz

Department of Engineering
Purdue University Calumet
2200 169th Street
Hammond, Indiana 46323

Telephone: 219-989-2473
e-mail habramowitz@worldnet.att.net

Biographical Information:

Harvey Abramowitz received a B.S. in Materials Science from the Henry Krumb School of Mines, School of Engineering and Applied Science, Columbia University. He completed M.S. and D.Eng.Sc. degrees from the same school in extractive metallurgy/mineral engineering. Prior to coming to Purdue University Calumet, he was a Research Engineer at Inland Steel Research Laboratories and Visiting Professor at the University of Missouri, Rolla. This year, he is a Visiting Scholar at Northwestern University. Dr. Abramowitz is an Associate Professor of Mechanical Engineering and is responsible for the materials sciences courses. Major areas of research are the treatment of waste streams for metal recovery and the cryogenic treatment of steels.



Determination of Viscosity Using a Falling Sphere Viscometer

Harvey Abramowitz
Department of Engineering
Purdue University Calumet
Hammond, IN 46323

Key Words:

Viscosity, Falling Sphere Viscometer, Glycerin

Prerequisite Knowledge:

The student
1. should be familiar with PC's and spreadsheets.
2. should be familiar with micrometers and dial calipers.

Objectives:

1. To introduce the student to the concept of viscosity.
2. To demonstrate one method for determining viscosity of a liquid.
3. To determine the viscosity of glycerin.
4. To introduce the student to experimental uncertainty.
5. To introduce the use of standards (i.e., literature values) to verify experimental results.

Equipment and Supplies:

1. Scientific Grade Glycerin (Fisher Scientific)
2. 2000 ml Graduated Cylinder
3. Balance
4. Stopwatch
5. Micrometer
6. Dial Caliper
7. Temperature Meter with J or K Thermocouples
8. Thermometer
9. Meter or Yard Stick
10. Cotton Gloves
11. Rubber Gloves
12. Small Spheres of Various Materials and Sizes
    a. Materials: Stainless Steel, Brass, and Glass
    b. Sizes (diameters)

Stainless Steel (440)	1/8", 3/16", 1/4"
Brass	1/8"
Glass	3 and 6 mm

13. Forceps
14. PC with Spreadsheet Program
15. Masking Tape, or
16. Marking Pen that can write on glass, such as an overhead marking pen

Introduction:

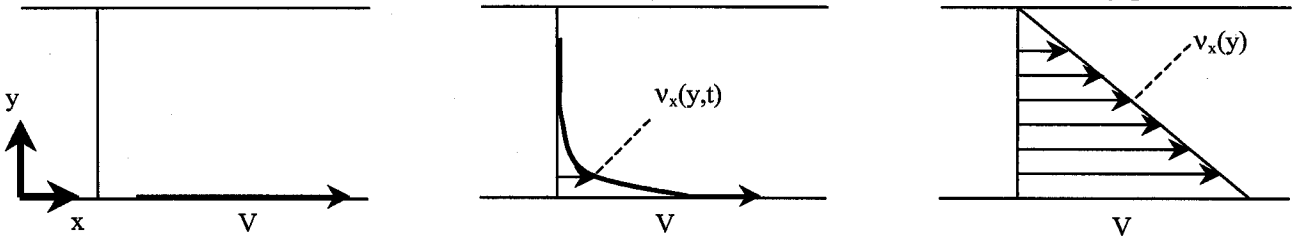
Viscosity is an important property of fluids (liquids and gases). It can be considered a measure of the resistance of a fluid to flow. Knowledge of a fluid's viscosity can be critical in optimizing industrial applications and processes. As examples, it is important to know the viscosity of (1) liquids used as lubricants, (2) molten metals and slags when smelting, refining, and processing metals, and (3) glasses during their production and processing. Perhaps one of the most familiar applications of viscosity knowledge is in the consumer's choice of an automobile engine oil. Nowadays, a single all season weight oil is typically used. However, it wasn't that many years ago that different weight oils were used in the summer and winter seasons. This was due to the fact that viscosity is highly temperature dependent, and, for a liquid, decreases as the temperature is raised. Hence, a heavier weight oil was used in the summer and a lighter weight engine oil used in the winter.

Theory:

The following explanations have been excerpted from Poirier and Geiger.[1,2]

Newtonian Fluids

Consider a fluid between two parallel plates (Fig. 1). The upper plate is stationary and the lower one is set in motion with a velocity V at time zero. From experience, it is known that the fluid adjacent to the plates will have the same velocity as the plates themselves. Hence the fluid adjacent to the lower plate moves with a velocity V, while that adjacent to the upper plate has null velocity. As time proceeds, the fluid gains momentum, and after sufficient time has elapsed steady state is reached, in which, in order to keep the lower plate in motion with the velocity V, a force F must be maintained, and an equal but opposite force is exerted on the stationary plate.



t = 0 Lower plate set in motion

Small t Velocity buildup in unsteady flow

Large t Final velocity distribution in steady flow

Fig. 1 Laminar flow of fluid between parallel plates

At steady state, for plates of area A, and laminar flow, the force is expressed by

$$\frac{F}{A} = \eta \frac{V}{Y} \qquad \text{Eq. 1}$$

where Y = distance between plates, and
η = constant of proportionality

The force system as described is pure shear, and the force per unit area (F/A) is the shear stress. At steady state, when the velocity profile is linear, V/Y exactly equals the constant velocity gradient dv_x/dy and the shear stress τ_{yx} between any two thin layers of fluid may be expressed as

$$\tau_{yx} = -\eta \frac{dv_x}{dy} \qquad \text{Eq. 2}$$

Equation 2 may alternatively be interpreted in terms of momentum transport. Picture the fluid as a series of thin layers parallel to the plates. By the shearing action each layer causes the layer directly above it to move. Thus, momentum is transported in the y-direction. The subscripts of τ_{yx} refer to this direction of momentum transport (y) and the velocity component being considered (x-direction). The minus sign in Eq. (2) reflects the fact that momentum is transferred from the lower layers of fluid to the upper layers, that is, in the positive y-direction. In this case, dv_x/dy is negative, so that the minus sign makes τ_{yx} positive. This follows the generally accepted convention for heat transfer, in that momentum flows in the direction of decreasing velocity, just as heat flows from hot to cold.

The period between t = 0, when the lower plate is set into motion, and large t, when steady state is reached, is called the transient period. During the transient period, v_x is a function of both time and position. The empirical relationship described is known as *Newton's Law of Viscosity,* and defines the constant of proportionality, η, as the viscosity.

The units of η are given in both SI and English units, because both are still in use.

$$\eta = \frac{N\ m^{-2}}{(m\ s^{-1})(m^{-1})} = N\ s\ m^{-2} \qquad \text{Eq. 3}$$

$$\eta = \frac{lb_f\ ft^{-2}}{(ft\ hr^{-1})(ft^{-1})} = lb_f\ hr\ ft^{-2} \qquad \text{Eq. 4}$$

or

$$\eta = \frac{(lb_m\ ft\ hr^{-2})(ft^{-2})}{(ft\ hr^{-1})(ft^{-1})} = lb_m\ hr^{-1}\ ft^{-1} \qquad \text{Eq. 5}$$

In the cgs system of units, the *poise* (P) is used, in which

$$1 \text{ poise (P)} = 1 \text{ dyn sec cm}^{-2}$$
$$= 1 \text{ gm cm sec}^{-2} \text{ sec cm}^{-2}$$
$$= 1 \text{ gm sec}^{-1} \text{ cm}^{-1}$$

The *centipoise* (cP) is probably the most common unit tabulated for viscosity. It equals 0.01 poise, and is the viscosity of water at 20.2 °C (68.4 °F). Thus the value of the viscosity in centipoises is an indication of the viscosity of the fluid relative to that of water at 20.2 °C. Viscosity in N s m^{-2} is 10^3 times viscosity in cP.

Falling Sphere Viscometer

If a sphere is falling through a liquid, it is possible to calculate the viscosity of the liquid. In order to do so, a force balance on the sphere is made (Fig. 2).

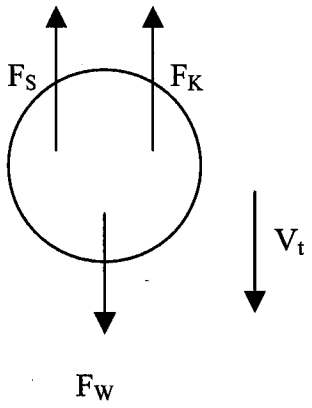


Fig. 2 Force Balance on Sphere Falling Through a Liquid

The forces acting upwardly on the sphere are the buoyant force (F_S) and the drag force (F_K). The force in the downward direction (F_W) is due to the weight of the sphere. These forces have the following values:

$$F_S = \frac{4}{3}\pi R^3 \rho g \qquad \text{Eq. 6}$$

which is the force exerted even if the fluid is stationary.

$$F_K = 6\pi\eta R V_t \qquad \text{Eq. 7}$$

which is the force associated with fluid movement, and is commonly known as Stoke's Law for creeping flow around a sphere. Stoke's Law applies over a very narrow range of conditions such as those present in this experiment, where small spherical particles are moving through a stagnant fluid.

and $$F_W = \frac{4}{3}\pi R^3 \rho_S g$$ Eq. 8

where
R = sphere radius
ρ = fluid density
g = acceleration due to gravity
η = viscosity
V_t = terminal velocity
ρ_S = sphere density

The force balance is: $$F_S + F_K = F_W$$ Eq. 9

or $$\frac{4}{3}\pi R^3 \rho g + 6\pi\eta R V_t = \frac{4}{3}\pi R^3 \rho_S g$$ Eq. 10

Therefore, $$\eta = \frac{\frac{4}{3}\pi R^3 g(\rho_S - \rho)}{6\pi R V_t}$$ Eq. 11

or $$\boxed{\eta = \frac{2R^2 g(\rho_S - \rho)}{9V_t}}$$ Eq. 12

This result is valid only if $2RV_t\rho/\eta$ is less than approximately unity.

$$\frac{2RV_t\rho}{\eta} < 1$$ Eq. 13

The above quantity is known as the Reynolds (Re) number and is typically between 0.1 and 0.2 for this experiment.

If the column containing the fluid has a finite diameter, the column boundaries will indicate an apparent terminal velocity higher than that obtained for an infinite fluid. The measured velocity should be corrected as follows:[3]

$$V_t = \left(1 + 2.4\frac{D}{D_c}\right)V_m$$ Eq. 14

where
V_t = terminal velocity in an infinite fluid
V_m = measured terminal velocity
D = ball diameter
D_c = column diameter

Experimental Procedure:

1. Fill a 2000 ml graduated cylinder with glycerin.
2. Measure the temperature of the glycerin with a thermometer or thermocouple.
3. Choose a ball material and size. Try 5 or 6 different types of balls. Take a minimum of three (3) balls for each type chosen.
4. Measure the diameters (D = 2R) of the balls using a micrometer or caliper.
5. Determine the average densities of these balls by dividing the weight of each ball by its volume ($4/3\ \pi R^3$ or $\pi D^3/6$).
   If the balance used cannot weigh individual balls, weigh several balls together. Use at least three (3) balls.
6. Mark two points on the cylinder so that they are at least 20-25 cm apart. Use tape or a marking pen. Make sure that at the top point the terminal velocity is reached.
7. Let the balls drop one at a time in the fluid and measure the time for a sphere to fall between the two points on the graduated cylinder using a stopwatch. The measured terminal velocity is the distance between the two points divided by the drop time.
8. Calculate the fluid viscosity. Include the correction for terminal velocity.

Results:

Put the data and calculations into a spreadsheet. Use the following column headings:

Material Diameter (in) Diameter (cm) Weight (g) Volume (g/cm) Density (g/cm^3) Time (s)

V_m (cm/s) D_c (in) D_c (cm) D/D_c V_t (cm/s) Viscosity (P) Viscosity (cP) Temperature (^oC)

Day/Group

The density of glycerin[4] is: $\rho = 1.2613\ g/cm^3$ for $4\ ^oC \leq T \leq 20\ ^oC$

For temperatures greater than 20 °C, the density will be assumed to also have this value. Room temperature will not usually be greater than 25 °C.

Typical results are given in Tables I and II. The data on which these tables are based is found in the Appendix .

Discussion:

The discussion should include answers to the following questions.

1. Compare the experimental results to published values.[5] Use the values below.

T (°C)	η (cP)
0	12,110
6	6,260
15	2,330
20	1,490

25	954
30	629

Plot this data to see the strong dependence of viscosity on temperature (Fig. 3). Do a linear interpolation to find the reported viscosity for the actual temperature of the experiment.
Compare the average experimental viscosity to the reported viscosity. Include an error analysis.

Viscosity is strongly dependent on temperature. To obtain values for comparison purposes, values of viscosity between 20 and 25 °C are calculated using a linear interpolation (Table III). For this experiment with T=22 °C, the average η *= 1126 cP with an overall error of 12%.*

2. Is the experimental viscosity a function of the sphere materials?

Based on Table I, it appears that the glass spheres led to twice the error value of either brass or stainless steel. The viscosity should be the same regardless of the material.

3. Is the experimental viscosity a function of the sphere size?

Tables I and II in conjunction with Table III, show that the greatest error occurred using the 0.6 cm diameter glass spheres. Viscosity should be independent of sphere size.

4. Obtain data from other groups. Is the experimental viscosity a function of temperature?

When more than one group performs this experiment, a range of experimental temperatures will result, especially if the groups do these trials on different days. The viscosities determined should depend on the temperature at measurement.

5. What are the possible experimental errors that could account for any differences between the experimental and published values?

A number of sources that may account for any errors have been identified. These are:

(a) *Contamination of the glycerin has appeared as the biggest source of error. Water absorption can drastically lower the viscosity, by as much as 50%. During the course of even ½ hour of experimentation, the viscosity may steadily decline with exposure to the atmosphere. If the balls are handled without gloves, natural oils from the body may also adversely affect the results.*

(b) *If the spheres are not perfectly round, then the equations used would no longer apply. An example of this may be the 0.6 cm glass beads, since the error values are twice those of the other materials. In the past, aluminum shot was used. This shot led to errors much larger than any other spheres. Upon inspection, these balls proved to be misshapen spheres. Consequently, aluminum shot is no longer used.*

(c) *Human errors in timing the descent of the spheres. For larger and denser spheres, the time for descent is much smaller. Hence, any error in starting or stopping the watch would lead to a greater error in the recorded time.*

(d) *When viewing the descent past the marking on the cylinder, if the experimenter's eyes are not at the correct angle, there could be some errors due to parallax.*

6. Do you have any recommendations to improve this experiment?

(a) *Check the balls for possible eccentricity by taking low magnification photomicrographs.*

(b) *To reduce the wall affect variability, a funnel can be placed at the top of the graduated cylinder to center the ball delivery.*

(c) *Measure the time for the balls to descend by videotaping the fall, followed by analysis of the tape. Such a method could help to decrease the uncertainty in the time measurements. However, the experiment would become more complicated and expensive.*

(d) *Use much larger cylinders to obtain more accurate results. The purpose of this particular setup was to show that acceptable values (within 12%) of viscosity can be obtained using a very portable apparatus. This means that multiple stations can be easily used in the laboratory. At Purdue University Calumet, this experiment is done in a freshman engineering class (maximum of 25 students per laboratory section) using a maximum of six stations.*

Conclusions:

1. The viscosity of glycerin at a temperature of 22 °C was determined to be 1126 cP, which is within 12% of the published value.
2. The viscosity of a fluid can be experimentally determined using a simple falling sphere viscometer.

References:

1. G.H. Geiger and D.R. Poirier, Transport Phenomena in Metallurgy, Reading, MA: Addison-Wesley Publishing Co., 1973, pp. 5-7, 68-70.
2. D.R. Poirier and G.H. Geiger, Transport Phenomena in Materials Processing, Warrendale, PA: TMS, 1994, pp. 4-6, 71.
3. E.H.Buyco and T.N. Tran, ME313 Lab-Manual, Fluid Mechanics Laboratory, Hammond, IN: Purdue University Calumet, 1995, p. 65.
4. Handbook of Chemistry and Physics, 49th ed., Cleveland, OH: CRC, 1968, p. C-338.
5. Ibid., p. F-40.

TABLE I
Viscosity of Glycerin as Function of Sphere Material
(T = 22 °C)

Material	η (cP)	Error (%)
Brass	1160	9
Stainless Steel	1158	9
Glass	1043	18
AVERAGE of all trials	**1126**	**12**

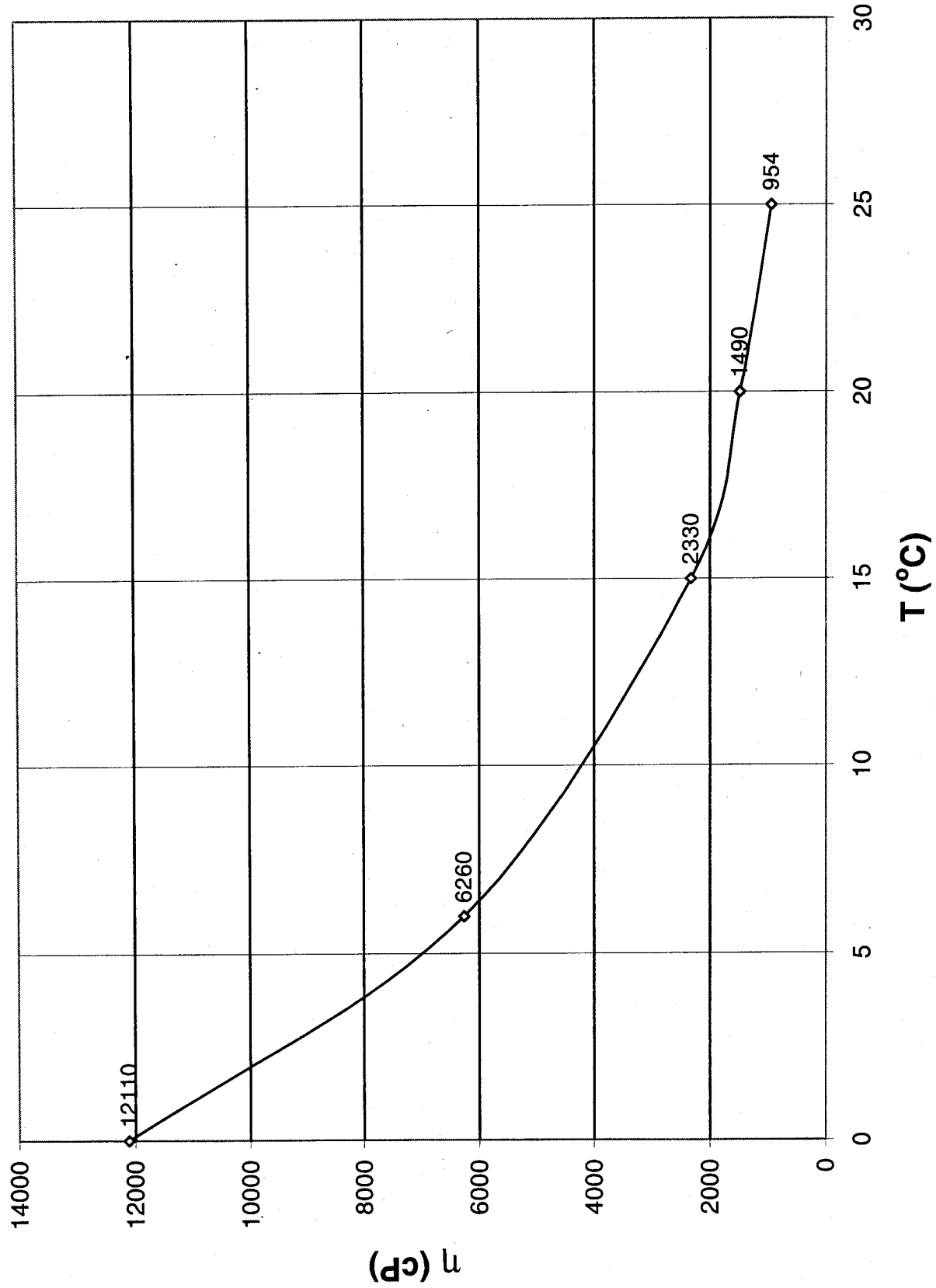
TABLE II
Viscosity of Glycerin as Function of Sphere Size
(T = 22 °C)

Diameter (cm)	η (cP)	Error (%)
0.3	1121	12
0.3175	1186	7
0.4763	1141	11
0.6	966	24
0.6350	1140	11
AVERAGE of all trials	**1126**	**12**

TABLE III
Viscosity of Glycerin as Function of Temperature
Linear Interpolation of Published Values

T (°C)	η (cP)
21	1383
22	1276
23	1168
24	1061

Fig. 3 Viscosity of Glycerin as Function of Temperature



APPENDIX : VISCOSITY OF GLYCERIN

MATERIAL	DIAMETER (D)		WEIGHT	VOLUME	DENSITY	TIME	V_m	D_c	D_c	D/D_c	V_t	VISCOSITY		T	DAY/
	inches	cm	g	cm^3	g/cm^3	s	cm/s	inches	cm		cm/s	P	cP	^oC	GROUP
Brass	0.1250	0.3175	0.150	0.0167	8.9553	6.24	3.21	3.125	7.938	0.040	3.51	12.02	1202	22	Tuesday
Brass	0.1250	0.3175	0.150	0.0167	8.9553	6.34	3.15	3.125	7.938	0.040	3.46	12.21	1221	22	
Brass	0.2500	0.6350	1.150	0.1340	8.5822	1.70	11.76	3.125	7.938	0.080	14.02	11.46	1146	22	Group 6
Brass	0.2500	0.6350	1.150	0.1340	8.5822	1.77	11.30	3.125	7.938	0.080	13.47	11.93	1193	22	
SS	0.1250	0.3175	0.125	0.0167	7.4628	7.02	2.85	3.125	7.938	0.040	3.12	10.90	1090	22	
SS	0.1250	0.3175	0.125	0.0167	7.4628	7.11	2.81	3.125	7.938	0.040	3.08	11.04	1104	22	
440 SS	0.1875	0.4763	0.425	0.0565	7.5181	3.30	6.06	3.125	7.938	0.060	6.93	11.14	1114	22	
440 SS	0.1875	0.4763	0.425	0.0565	7.5181	3.30	6.06	3.125	7.938	0.060	6.93	11.14	1114	22	
440 SS	0.2500	0.6350	1.000	0.1340	7.4628	2.06	9.71	3.125	7.938	0.080	11.57	11.76	1176	22	
440 SS	0.2500	0.6350	1.000	0.1340	7.4628	2.07	9.66	3.125	7.938	0.080	11.52	11.82	1182	22	
Glass		0.3000	0.035	0.0141	2.4770	41.49	0.48	3.125	7.938	0.038	0.53	11.33	1133	22	
Glass		0.3000	0.035	0.0141	2.4770	39.80	0.50	3.125	7.938	0.038	0.55	10.87	1087	22	
Glass		0.6000	0.250	0.1130	2.2116	11.09	1.80	3.125	7.938	0.076	2.13	8.74	874	22	
Glass		0.6000	0.250	0.1130	2.2116	11.04	1.81	3.125	7.938	0.076	2.14	8.70	870	22	
													1108	AVE	
Brass	0.1250	0.3175	0.150	0.0167	8.9553	6.22	3.22	3.125	7.938	0.040	3.52	11.98	1198	22	Tuesday
Brass	0.1250	0.3175	0.150	0.0167	8.9553	6.24	3.21	3.125	7.938	0.040	3.51	12.02	1202	22	
Brass	0.2500	0.6350	1.100	0.1340	8.2091	1.72	11.63	3.125	7.938	0.080	13.86	11.00	1100	22	Group 3
Brass	0.2500	0.6350	1.100	0.1340	8.2091	1.75	11.43	3.125	7.938	0.080	13.62	11.20	1120	22	
SS	0.1250	0.3175	0.150	0.0167	8.9553	7.34	2.72	3.125	7.938	0.040	2.99	14.14	1414	22	
SS	0.1250	0.3175	0.150	0.0167	8.9553	7.33	2.73	3.125	7.938	0.040	2.99	14.12	1412	22	
440 SS	0.1875	0.4763	0.450	0.0565	7.9603	3.66	5.46	3.125	7.938	0.060	6.25	13.23	1323	22	
440 SS	0.1875	0.4763	0.450	0.0565	7.9603	3.36	5.95	3.125	7.938	0.060	6.81	12.15	1215	22	
440 SS	0.2500	0.6350	1.050	0.1340	7.8359	1.92	10.42	3.125	7.938	0.080	12.42	11.62	1162	22	
440 SS	0.2500	0.6350	1.050	0.1340	7.8359	1.82	10.99	3.125	7.938	0.080	13.10	11.02	1102	22	
Glass		0.3000	0.035	0.0141	2.4770	42.54	0.47	3.125	7.938	0.038	0.51	11.62	1162	22	
Glass		0.3000	0.035	0.0141	2.4770	43.52	0.46	3.125	7.938	0.038	0.50	11.88	1188	22	
Glass		0.6000	0.250	0.1130	2.2116	11.20	1.79	3.125	7.938	0.076	2.11	8.83	883	22	
Glass		0.6000	0.250	0.1130	2.2116	11.31	1.77	3.125	7.938	0.076	2.09	8.92	892	22	
													1170	AVE	

MATERIAL	DIAMETER (D)		WEIGHT	VOLUME	DENSITY	TIME	V_m	D_c	D_c	D/D_c	V_t	VISCOSITY		T	DAY/
	inches	cm	g	cm^3	g/cm^3	s	cm/s	inches	cm		cm/s	P	cP	^oC	GROUP
Brass	0.1250	0.3175	0.150	0.0167	8.9553	5.84	3.42	3.000	7.620	0.042	3.77	11.21	1121	22	Thursday
Brass	0.1250	0.3175	0.150	0.0167	8.9553	5.74	3.48	3.000	7.620	0.042	3.83	11.02	1102	22	
Brass	0.2500	0.6350	1.150	0.1340	8.5822	1.55	12.90	3.000	7.620	0.083	15.48	10.38	1038	22	Group 1
Brass	0.2500	0.6350	1.150	0.1340	8.5822	1.59	12.58	3.000	7.620	0.083	15.09	10.65	1065	22	
SS	0.1250	0.3175	0.125	0.0167	7.4628	6.66	3.00	3.000	7.620	0.042	3.30	10.30	1030	22	
SS	0.1250	0.3175	0.125	0.0167	7.4628	6.86	2.92	3.000	7.620	0.042	3.21	10.61	1061	22	
440 SS	0.1875	0.4763	0.425	0.0565	7.5181	3.02	6.62	3.000	7.620	0.063	7.62	10.14	1014	22	
440 SS	0.1875	0.4763	0.425	0.0565	7.5181	3.08	6.49	3.000	7.620	0.063	7.47	10.35	1035	22	
440 SS	0.2500	0.6350	1.025	0.1340	7.6493	1.88	10.64	3.000	7.620	0.083	12.77	10.99	1099	22	
440 SS	0.2500	0.6350	1.025	0.1340	7.6493	1.95	10.26	3.000	7.620	0.083	12.31	11.39	1139	22	
Glass		0.3000	0.035	0.0141	2.4770	37.81	0.53	3.000	7.620	0.039	0.58	10.29	1029	22	
Glass		0.3000	0.035	0.0141	2.4770	36.87	0.54	3.000	7.620	0.039	0.59	10.03	1003	22	
Glass		0.6000	0.275	0.1130	2.4328	10.07	1.99	3.000	7.620	0.079	2.36	9.72	972	22	
Glass		0.6000	0.275	0.1130	2.4328	10.35	1.93	3.000	7.620	0.079	2.30	9.99	999	22	
													1051	AVE	
Brass	0.1250	0.3175	0.150	0.0167	8.9553	6.59	3.03	3.150	8.001	0.040	3.32	12.70	1270	22	Thursday
Brass	0.1250	0.3175	0.150	0.0167	8.9553	6.44	3.11	3.150	8.001	0.040	3.40	12.41	1241	22	
Brass	0.2500	0.6350	1.150	0.1340	8.5822	1.85	10.81	3.150	8.001	0.079	12.87	12.49	1249	22	Group 2
Brass	0.2500	0.6350	1.125	0.1340	8.3956	1.67	12.01	3.150	8.001	0.079	14.30	10.95	1095	22	
SS	0.1250	0.3175	0.125	0.0167	7.4628	7.50	2.67	3.150	8.001	0.040	2.92	11.65	1165	22	
SS	0.1250	0.3175	0.125	0.0167	7.4628	7.38	2.71	3.150	8.001	0.040	2.97	11.47	1147	22	
440 SS	0.1875	0.4763	0.425	0.0565	7.5181	3.40	5.88	3.150	8.001	0.060	6.72	11.49	1149	22	
440 SS	0.1875	0.4763	0.425	0.0565	7.5181	3.44	5.81	3.150	8.001	0.060	6.64	11.63	1163	22	
440 SS	0.2500	0.6350	1.025	0.1340	7.6493	2.03	9.85	3.150	8.001	0.079	11.73	11.96	1196	22	
440 SS	0.2500	0.6350	1.025	0.1340	7.6493	2.00	10.00	3.150	8.001	0.079	11.90	11.78	1178	22	
Glass		0.3000	0.035	0.0141	2.4770	43.54	0.46	3.150	8.001	0.037	0.50	11.90	1190	22	
Glass		0.3000	0.035	0.0141	2.4770	43.09	0.46	3.150	8.001	0.037	0.51	11.77	1177	22	
Glass		0.6000	0.275	0.1130	2.4328	11.69	1.71	3.150	8.001	0.075	2.02	11.37	1137	22	
Glass		0.6000	0.275	0.1130	2.4328	11.25	1.78	3.150	8.001	0.075	2.10	10.95	1095	22	
													1175	AVE	

TWISTY GLUE STICKS OR TORSIONAL CHARACTERISTICS OF HOT MELT ALL PURPOSE GLUE STICKS

Alan K. Karplus

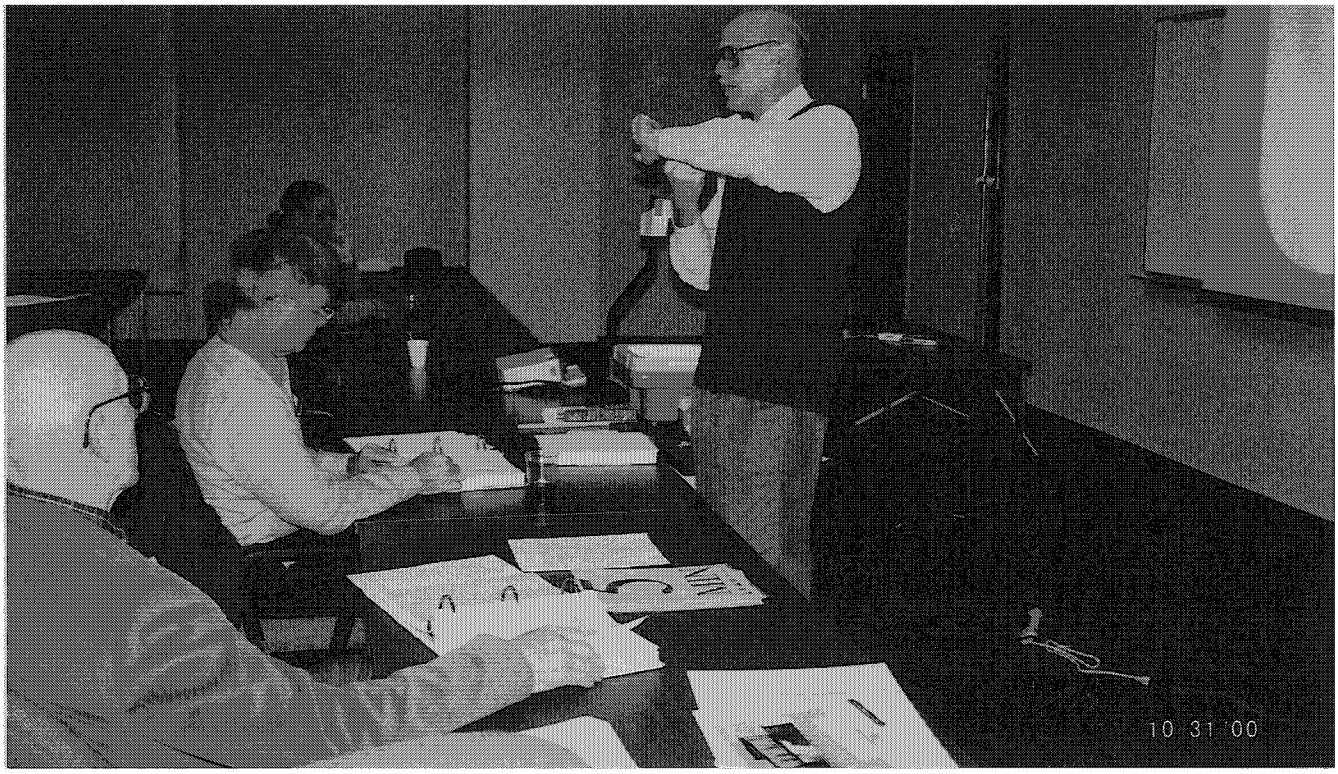
Department of Mechanical Engineering
Western New England College
1215 Wilbraham Road
Springfield, Massachusetts 01119-2684

Telephone: 413-782-1220
e-mail akarplus@wnec.edu

Bibliography:

ALAN K. KARPLUS

Alan K. Karplus is Professor of Mechanical Engineering at Western New England College, Springfield, Massachusetts. He has a Bachelor's degree for Tufts College, a Master's degree from Iowa State University, and a Ph.D. from Colorado Sate University. He has been involved with the freshman engineering program, coordinates the senior mechanical engineering laboratory program, has taught Materials Science and supervises M.E. Senior Projects. His interests include materials and design. He is a member of ASME and ASEE. He has contributed to the National Educators' Workshop and ASEE Annual Conference for several years.



TWISTY GLUE STICKS

or

Torsional Characteristics of Hot Melt All Purpose Glue Sticks

Alan K. Karplus
Department of Mechanical Engineering
Western New England College
1215 Wilbraham Road
Springfield, MA 01119-2684

Key Words:
Hot Melt Glue Sticks, Polymer Properties, Torsion Tests

Prerequisite Knowledge:
Have an idea about how a thermoplastic hot melt glue stick can be twisted and reverse twisted without failure, and severely twisted to cause the stick to break apart.

Objective:
To work as a team member in the collection of data, to make plots for near constant rate twisting and (reverse twisting) of traditional hot melt glue sticks, and to show features which are unique to these thermoplastic products:

- Shear stress - shear strain plot
- Shear work done to fail sample
- Recoverable work and hystersis when sample is not failed
- Rate of loading

Equipment and Materials:

1. Ten inch long hot melt glue sticks. These are readily available at home centers as Arrow™ All Purpose Clear Glue Sticx (Model AP10) which come in a box of 12 - 10 inch sticks. Some suppliers will carry a variety such as All purpose, Slow set, and white caulk/sealer/glue.
2. Torsion test apparatus. See the Appendix to this paper for construction of a torsion tester made with Flex-angle™, two ½ inch diameter Jacobs drill chucks, two ½ inch diameter fine thread 2 ½ inch long bolts, miscellaneous bolts and washers, one 4 inch diameter Lazy Susan bearing, and chipboard disks.
3. C-clamps to hold the torsion tester base to a table.
4. Safety Goggles
5. Heavy work gloves
6. Load scale for loads to 10 pounds or 5 kg. A 20 Newton scale works, also.
7. Vernier caliper.
8. Black or dark color Magic marker.
9. Data page with 25 lines and nine columns. Measurements are taken at 90 degree rotation increments starting at a value of zero listed in the first column. The remaining columns are used in pairs to record load and unload. Be sure to label columns and include units of measure selected.

10. A Spreadsheet such as EXCEL™. All work performed on the spreadsheet can be done by hand.
11. When the computations are to be done by hand, computation paper and several pieces of linear graph paper with 20 divisions to the inch are needed.

Introduction:
The initial challenge is to hold a glue stick in your hand and to twist it about its long axis. This is difficult to do! One objective is to design and build an apparatus which will twist the glue stick and other samples. A torsion test apparatus has been designed from readily available parts. See the Appendix for detailed construction instruction of an inexpensive (less than $50.00) torsion tester made with Flex-Angle™. This unit requires two disks: one 4 inch diameter and one 8 inch diameter each with a circumferential groove so that the same load scale can be used and the applied torque can be doubled. In case a different torque range is of interest another disk diameter can be made. For the All Purpose Arrow Glue sticks the four inch diameter disk with torques of up to 2 inches times 10 pounds can be applied. In fact, the load scale used was calibrated in NEWTONS so that a maximum of 2 inches times 20 Newtons divided by 4.448 Newtons per pound for 5.50 inch-pounds torque could be applied.

Procedure:

A. Equipment Set Up:
The idea is to cut the ½ inch diameter 10 inch long glue stick into two 5 inch long sticks. Both 5 inch long sticks are to be tested. On the surface of each stick draw a line parallel to the axis on the surface with a 'Magic' felt tip marker. This is a reference line.

The First Test is to twist the glue stick to failure. It is helpful to designate that the torsion wheel will be loaded so that it rotates clockwise as the experimenter looks down on the wheel. Now place one 5 inch long stick into the tester by inserting - one at a time - an end of the stick all the way into the bottom chuck (1 inch of insertion) and clamp the chuck hand tight onto the stick followed by four revolutions of the Jacobs key in the chuck to assure capture of the glue stick end. Repeat this for the second end into the top chuck (1 inch of insertion). Prior to tightening this chuck align the angle position indicator 15 degrees counterclockwise to the 0 degree start position. This is to be sure to start with a 0 angle reading. There are angle markings on the torsion wheel at 0, 90, 180, 270 and 360 or the next zero (0) degree mark. Loads are to be read at each of these positions while the load is applied to the 3 inch gage length glue stick and recorded. Note that on this primitive apparatus when six turns of 360 degrees torque wheel are anticipated a length of 4 inches times Pi (3.14157) times 6 or some 75 inches of fishing line coiled on the torque wheel will be unwound. Be sure to provide physical space for this when mounting the apparatus on a table. Also be sure the table will not move. When the stick breaks the wheel will spin. Gently and rapidly stop the spinning wheel by catching the disk to avoid unwinding much fish line. A gloved hand works well for this.

The data is to be reduced to applied torque and angle of twist which are to be plotted first. After some computations an engineering shear stress against shear strain plot can be made. The work done on the sample can be computed and plotted, too. Also, the rate of load (torque) application can be investigated and a plot made.

The Second Test is based on observations made of the data collected in the First Test. Find the 'elastic' recoverable region of the response of the first five inch long stick to twisting. This will be readily found when the load (torque) applied levels off, but does not fall in magnitude. The 'elastic' recoverable region has been found.

The Second Test begins with loading and recording the load (torque) and angle of twist at each 90 degrees clockwise the stick twist up to and including the leveled-off load (torque). Then the sample is to be unloaded while the applied load (torque) and angle of twist are recorded. As in the First Test, mount the 5 inch long stick with 1 inch inserted into each chuck for a 3 inch gage length is twisted with load (torques applied at constant radius) recorded at 90 degrees of twist increment. The data is to be reduced so that applied torque against angle of twist can be plotted for both the clockwise twisting (UpLoad) of the sample when looking down on the top of the tester and the counterclockwise (DwLoad) release of applied torque on the glue stick. Then an engineering shear stress against shear strain plot can be made after computation of shear strain and shear stress are made. Next the work done on the sample and the energy stored by the sample can be computed and plotted against shear strain. An hystersis coefficient can also be computed. Finally, the rate of clockwise applied torque application in contrast to rate of released torque (counterclockwise rotation) can be investigated. This latter part of the experiment up-twist and down-twist follows the presentation of Stretchy "Elastic" Bands, Stretchy "Elastic" Bands II, and Stretchy "Elastic" Bands III presented as NEW: UpDate: 1997, 1998, and 1999 experiments, respectively by the author.

B. Computations:

The computations to be made for the First Test plot of applied torque against angle of twist to sample failure requires the applied load to be multiplied by the Radius of the torque wheel which is two inches. In addition, when English units are used a conversion from Newtons to Pounds is needed. The clockwise angle of twist increments need to be replaced by total angle so that 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180, 270 become 0, 90, 180, 270, 360, 450, 540, 630, 720, 810, 900, and 990 respectively. Assume six (6) revolutions are needed to twist the stick to failure so that 6 times 4 plus 1 lines on the data sheet are needed. Data sheet headings should be Twist Angle in degrees and Load in Newtons (which becomes Torque). The plot can readily be made in a spreadsheet environment.

The Second Test plot of engineering shear stress against engineering shear strain is required. The angle of twist is computed for the 1/4 inch radius test stick divided by the gage length of 3 inches selected in this work multiplied by the angle of twist in radians (one radian equals 180°/Pi or 57.30°). There are two Pi radians in one revolution. The shear strain is more complex and requires the application of a relationship which multiplies the applied torque by the radius of the sample divided by the area polar moment of inertia of the test stick. The polar moment of inertia is Pi (3.14157) times the diameter of the test stick raised to the fourth power divided by 64.

Measure the twisting work done by the area under the curve of shear stress against shear strain (the area under the UPLOAD line to failure). This represents the energy used to twist the glue stick. Compute the area under the curves with trapezoidal increments and then, sum these increments.

A spreadsheet cell should be used to store each trapezoidal area increment. The trapezoidal increment is computed by forming the average of 2 stresses and multiplying by the change in strain. The total area under the curve is the energy and can be found by adding the incremental areas in a column. Be sure to check UNITS to be sure they are consistent.

The computations to be made for the Second Test plot of applied torque against angle of twist includes the recoverable portion of the glue stick. Again, this requires the applied load to be multiplied by the radius of the torque wheel which is 2 inches. In addition, when English units are used a conversion from Newtons to Pounds is needed. The angle of twist increments need to be replaced by total angle so that 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180 become 0, 90, 180, 270, 360, 450, 540, 630, 720, 810, and 900 respectively. However, the maximum angle of twist is limited to the greatest recoverable twist angle as assessed by evaluation of the First Test, presented above. Recall this maximum position occurs when the torque starts to 'level-off'. There are now two curves: UPLOAD and DWLOAD. The plots can readily be made in a spreadsheet environment.

The second plot for the recoverable portion of the glue stick evaluation of engineering shear stress against engineering shear strain is required, the angle of twist computed for the 1/4 inch radius test stick divided by the gage length of 3 inches selected in this work multiplied by the angle of twist in radians (one radian equals 180°/Pi(3.14157) or 57.30°). There are two Pi radians in one revolution. The shear strain is more complex and requires the application of a relationship which multiplies the applied torque by the radius of the sample divided by the area polar moment of inertia of the test stick. The polar moment of inertia is Pie times the diameter of the test stick raised to the 4th power divided by 64. In this situation there are two curves: UPLOAD and DWLOAD.

When the work done, is considered, which is the area under the curve of shear stress against shear strain increments for the area under the UPLOAD line are computed separately from the DWLOAD line. These represent the energy used to twist and untwist the glue stick. Compute the area under the each curve with trapezoidal increments. First the up-twist load curve and then the down-twist load curve. A spreadsheet cell should be used to store each trapezoidal area increment, remember one for the UPLOAD and one for the DWLOAD. A trapezoidal increment is computed by forming the average of two stresses and multiplying by the change in strain. The total area under each curve can be found by adding the appropriate incremental areas in a column, and is the energy related to each curve. The difference between column totals (UPLOAD and DWLOAD) is found by subtraction and then divided by the total UPLOAD work to determine the portion of energy lost to internal friction or hystersis. Be sure to check UNITS.

C. Test Activities:

I. The first activity is to build an apparatus for torsion testing. This is detailed in the Appendix.

II. The second activity, the First Test, is the evaluation of a glue stick under clockwise torsional loading to failure.

1. Cut one ½ inch diameter 10 inch long glue stick into two 5 inch long sticks. Select one stick to test to failure (This is the First Test.). Torsional loads are to be placed on the stick by pulling on the load scale attached to the fish line wrapped around the torsion wheel and stored in the circumferential groove on the wheel. Load scale (torsion) readings are to be taken at each 90 degrees of wheel rotation. It is best to note the wheel markings 0, 90, 180, 270 and 0 again and

prepare the data sheet angle of twist column as 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180, etc. The number of total turns can be counted later. **Place safety glasses and gloves on the spring scale operator, and prepare the recorded for writing the data on the data sheet.** The approach is to twist the stick at a near constant rate, recording the load to twist the stick each added 90 degrees of twist until the stick is sheared apart and fails. At this juncture the torsion wheel will spin rapidly until you gently stop it by clutching the wheel with a gloved hand. Do not become frustrated if the fish line is inadvertently wrapped around the torsion wheel several times. In preparation for the next test, a careful unwinding and wrapping of the fish line into the torsion wheel grove works nicely, especially with patience. Assume six (6) revolutions are needed to twist the stick to failure so that 6 times 4 plus 1 lines on the data sheet are needed. Heading should be Twist Angle in Degrees and Load in Newtons (which becomes Torque). Run the test.

2. The next task is to convert the recorded angular twist angles of 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180, etc. into a ascending column of clockwise angles that increases with increments of 90 degrees 0, 90, 180, 270, 360, 450, 540, 630, 720, 810, 900, etc. Once this has been completed the appropriate load is converted to a torque in inch-pounds by dividing the applied load recorded in Newtons by 4.448 Newtons per pound and multiplying by the torsion wheel radius of 2 inches in the case of the 4 inch wheel. The converted data of angle of twist (degrees) and applied torque (in-lb.) should then be charted with angle of twist as the independent variable (horizontal or x-axis). Make an **XY**[1] or **Scatter Plot** of this data. Label this graph as Torsonal Load against Twist Angle for a General Purpose ½ inch Diameter Glue Stick.
3. Compute shear strain for the angles of twist by dividing the radius of the stick (1/4 inches) by the gage length (3 inches) and multiplying this value by the angle of twist in radians. The angle of twist in radians is found by dividing the angle of twist by 180 and multiplying by Pie (3.14157). For example 90 degrees is (90/180)*3.14157 or 1.57 radians. Next the shear stress is computed for each applied torque expressed in inch-pounds. This calculation requires the experimenter to multiply the torque by the radius of the twisted sample (¼ inches) and divide the quantity by the polar moment of inertia. The polar moment of inertia which a property of the geometry of the twisted member is found by dividing Pie (3.14157) times the diameter of the twisted member raised to 4th power and dividing by 64. The units are pounds per square inch. These computations are made for each angle of twist and accompanying torque to obtain the corresponding shear strain and shear stress. Make an **XY** or **Scatter Plot** of this data. The values of shear strain and shear stress are to be charted by plotting shear stress against shear strain as the independent variable to obtain the General Purpose Glue Stick Shear Stress-Strain Plot.
4. From the shear stress-strain data the computation of work done to fail the glue stick can be found. The best approach is to apply the trapezoidal rule of integration to determine the area under the shear stress-strain curve. On a spreadsheet this is achieved in two steps. First the incremental work done over an increment of an angle of twist is computed, and second the increments are summed. The units of work are inch-pounds per cubic inch of material (glue stick). Make an **XY** or **Scatter Plot** of this data.

---

[1] Be sure to make a plot of two variables and NOT a line chart as is the usual default setting on a spreadsheet.

5. With the Applied Torque and Angle of Twist data the rate of loading can be assessed by dividing an incremental change in Applied Torque by the corresponding increment of Angle of Twist. Make an **XY** or **Scatter Plot** of this data. If the values computed over the range of strains are constant, then the applied twisting of the glue stick was done in a 'constant' fashion. Recall this was one objective for the experiment. Were you successful? Also check the reference line on the sample. Is it still straight?

III. The third activity, the Second Test, is the evaluation of the General Purpose Glue Stick for recoverable features. The first step is to review the plot of Torsional load against Twist Angle plot (see Part II item 2, above.) and determine where the curve 'levels-off'. The approach is to load the glue stick and observe when the load (torque) starts to change and move from the peak of the recoverable portion[2] of the glue stick with the recoverable region being in the vicinity of the "elastic limit" familiar to those who test low carbon steel. Once this region has been 'sized', repeat the steps 1-5 in II above with modification to collect DWLOAD load and angle of twist. Remember the first DWLOAD load is the last UPLOAD load and both are at the same angle of twist.

1. Select the second half of the glue stick for the recoverable test - UPLOAD and DWLOAD the glue stick (This is the Second Test.). Torsional loads are to be placed on the stick by pulling on the load scale attached to the fish line wrapped around the torsion wheel and stored in the circumferential groove on the wheel. Load scale (torsion) readings are to be taken at each 90 degrees of wheel rotation. It is best to note the wheel markings 0, 90, 180, 270 and 0 again and prepare the data sheet Twist Angle column as 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180 which is 15 lines. This discussion assumes there are 3 1/2 turns until the load 'levels-off'. Label the next column UPLOAD (UPLOAD TORQUE) and the next column as DWLOAD (DWLOAD TORQUE). Remember that the last UPLOAD load is the *first* DWLOAD load and fill in the DWLOAD column is reverse as the stick untwists. **Place safety glasses and gloves on the spring scale operator, and prepare the recorded for writing the data on the data sheet**. The approach is to twist the stick at a near constant rate, recording the load to twist the stick each added 90 degrees of twist until the stick load 'levels-off' at which point the DWLOAD begins. Run the test.
2. The next task is to convert the recorded angular twist angles of 0, 90, 180, 270, 0, 90, 180, 270, 0, 90, 180, etc. into a ascending column of angles that increases with increments of 90 degrees 0, 90, 180, 270, 360, 450, 540, 630, 720, 810, 900, etc. Once this has been completed the appropriate load (UPLOAD AND DWLOAD) is converted to a torque (UPLOAD TORQUE and DWLOAD TORQUE) in inch-pounds by dividing the applied load recorded in Newtons by 4.448 Newtons per pound and multiplying by the torsion wheel radius of 2 inches in the case of the 4 inch wheel. The converted data of angle of twist (degrees) and applied torques (in-lb.) should then be charted with angle of twist as the independent variable (horizontal or x-axis). Make an **XY** or **Scatter Plot** of this data. Label this graph as Recoverable Torsonal Load against Twist Angle for a All Purpose ½ inch Diameter Glue Stick. There should be two curves: UPLOAD TORQUE and DWLOAD TORQUE.
3. As in Part II. compute the shear strain for the angles of twist by dividing the radius of the stick (1/4 inches) by the gage length (3 inches) and multiplying this value by the angle of twist in radians. The angle of twist in radians is found by dividing the angle of twist by 180 and multiplying by Pie (3.14157). For example 90 degrees is (90/180)*3.14157 or 1.57 radians.

---

[2] This is a judgment call and uses your Engineering skills.

Next the shear stress is computed for each applied torque expressed in inch-pounds. This calculation requires the experimenter to multiply the torque by the radius of the twisted sample (¼ inches) and divide the quantity by the polar moment of inertia. The polar moment of inertia which a property of the geometry of the twisted member is found by dividing Pie (3.14157) times the diameter of the twisted member raised to 4th power and dividing by 64. The units are pounds per square inch. These computations are made for each angle of twist and accompanying torque to obtain the corresponding shear strain and shear stress. Make an **XY** or **Scatter Plot** of this data. The values of shear strain and shear stress are to be charted by plotting shear stress against shear strain as the independent variable to obtain the General Purpose Glue Stick Recoverable Shear Stress-Strain Plot. Note the similarities between this and the Plot in 2, immediately above. Check the reference line on the sample. Is it still straight?

4. From the shear stress-strain data the computation of *work done to fail the glue stick* can be found. The best approach is to apply the trapezodial rule of integration to determine the area under the shear stress-strain curve. On a spreadsheet this is achieved in two steps. First the incremental work done over an angle of twist is computed, and second the increments are summed. The units of work are inch-pounds per cubic inch of material (glue stick). This process is to be done for both the UPLOAD TORQUE and the DWLOAD TORQUE. Make an **XY** or **Scatter Plot** of this data that shows two curves. The difference between column totals (total UPLOAD TORQUE work and total DWLOAD TORQUE work) is found by subtraction and then divided by the total LOADING TORQUE work to give the portion of energy lost to internal friction or hystersis. Be sure to check UNITS for consistency.
5. With the Shear stress-strain data the rate of UPLOAD TORQUE and rate of DWLOAD TORQUE can be assessed by dividing an incremental change in torsional stress by the corresponding increment of shear strain. Make an **XY** or **Scatter Plot** of this data. There should be two curves. If the values computed over the range of strains are constant or perhaps oscillating about a constant value, then the applied twisting of the glue stick was done in a 'constant' fashion. Recall this was one objective for the experiment. Were you successful?

Comments:

To aid the instructor with the execution of this experiment two test made on the halves of a 10 inch long General Purpose Glue Stick are presented.

1. Figure 1 presents the data for the First Test - a test to failure. In Figures 2, 3, and 4 are shown the LOADING, the torsional work and rate of loading curves, respectively. Shown in Figure 1 are the following: columns 1 and 2 the twist angle in degrees recorded as 0, 90, 180, 270, 0, 90, 180, etc. and the torsional loading load in Newtons applied at a radius of 2 inches; in columns 3 and 4 the total angle of twist in radians and torque in inch-pounds; in columns 5 and 6 the shear stain radians per radian and shear stress in pounds per square inch; in columns 7 and 8 incremental work and accumulated work with units of in-lb./in^3; in column 9 the rate of loading computation with units of in-lb. /radian.

Angle Degrees	Force Newtons	Shear Deformatn Radians	Torque Applied - in.lbs.	Shear Strain Rad./rad.	Up Shear Stress lbs./in.^2	Incrmtl Work Up lb in/In^3	Total Work Up lb in/In^3	UpRate in-lb/rad
0	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000
90	3.5	1.571	1.574	0.131	128.240	8.393	8.393	1.002
180	7	3.142	3.147	0.262	256.480	25.180	33.573	1.002
270	9	4.712	4.047	0.393	329.760	38.369	71.942	0.572
360	10.5	6.283	4.721	0.524	384.720	46.763	118.705	0.429
450	12.5	7.854	5.621	0.654	458.000	55.156	173.861	0.572
540	13.5	9.425	6.070	0.785	494.640	62.350	236.211	0.286
630	14	10.996	6.295	0.916	512.960	65.947	302.158	0.143
720	14.75	12.566	6.632	1.047	540.440	68.945	371.103	0.215
810	15.5	14.137	6.969	1.178	567.920	72.542	443.645	0.215
900	16	15.708	7.194	1.309	586.240	75.540	519.185	0.143
990	16	17.279	7.194	1.440	586.240	76.739	595.923	0.000
1080	16.5	18.850	7.419	1.571	604.560	77.938	673.861	0.143
1170	16.5	20.420	7.419	1.702	604.560	79.137	752.998	0.000
1260	15.5	21.991	6.969	1.833	567.920	76.739	829.736	-0.286
1350	14.75	23.562	6.632	1.963	540.440	72.542	902.278	-0.215
1440	14	25.133	6.295	2.094	512.960	68.945	971.223	-0.215
1530	15.25	26.704	6.857	2.225	558.760	70.144	1041.367	0.358
1620	15.5	28.274	6.969	2.356	567.920	73.741	1115.108	0.072
1710	16	29.845	7.194	2.487	586.240	75.540	1190.647	0.143
1800	16	31.416	7.194	2.618	586.240	76.739	1267.386	0.000
1890	17	32.987	7.644	2.749	622.880	79.137	1346.523	0.286
1980	16.5	34.558	7.419	2.880	604.560	80.336	1426.859	-0.143
2070	16	36.128	7.194	3.011	586.240	77.938	1504.796	-0.143
2160	16	37.699	7.194	3.142	586.240	76.739	1581.535	0.000
2250	17	39.270	7.644	3.272	622.880	79.137	1660.671	0.286
2340	16	40.841	7.194	3.403	586.240	79.137	1739.808	-0.286
2430	15.5	42.412	6.969	3.534	567.920	75.540	1815.348	-0.143

Figure 1. First Test 0.5 in. Dia. Glue Stick Test to Failure Data

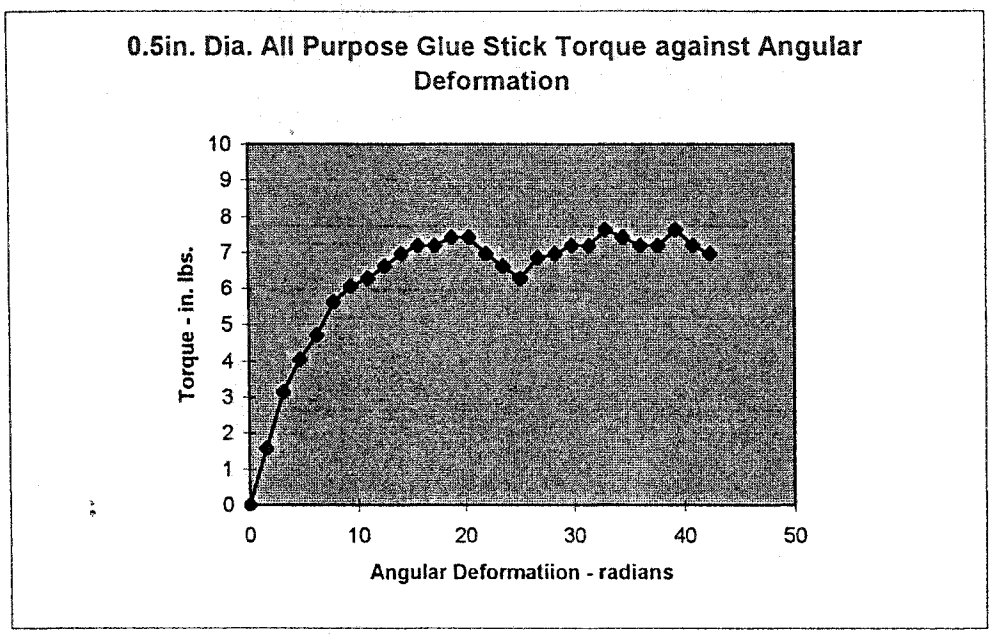


Figure 2. First Test 0.5 in Dia. All Purpose Glue Stick

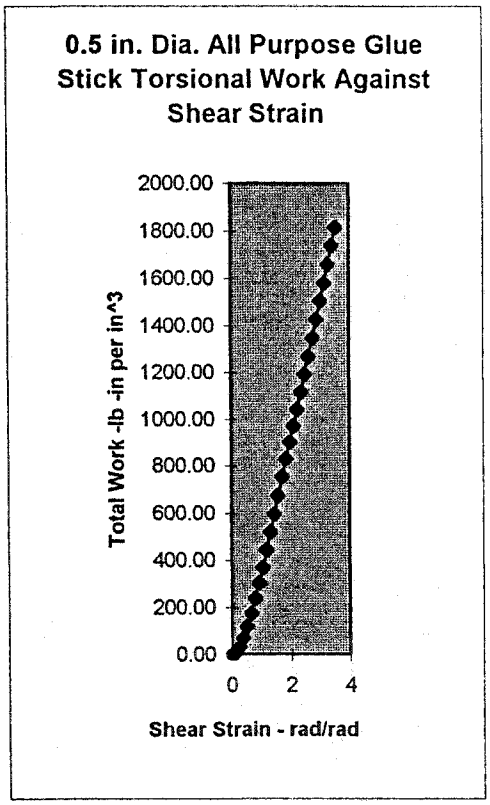


Figure 3. First Test Work Plot

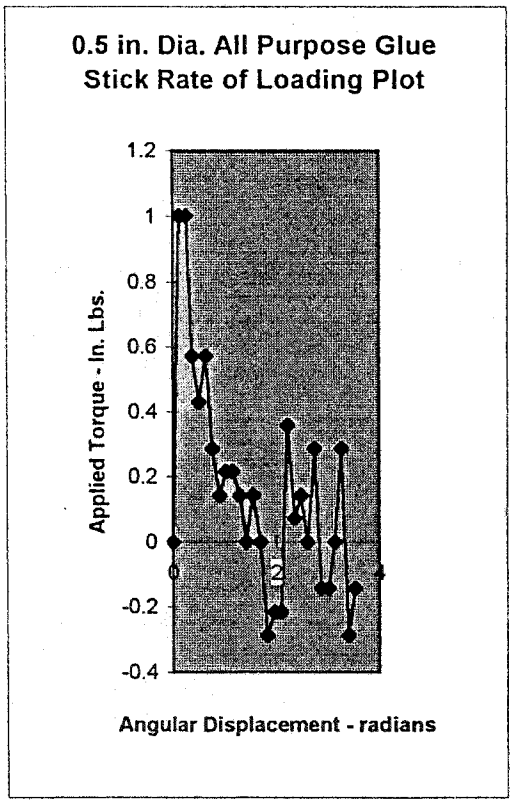


Figure 4. First Test Rate of Loading Plot

To present the computations in figure 1, a hand calculation for the 270° angular displacement is given:

- columns 1 and 2 contain collected raw data
- column 3 270 degrees is (270/180)*3.14157 or 4.712 radians,
- column 4 the load of 9.0 Newton is converted to a torque in inch-pounds by dividing the applied 9.0 Newton load recorded in Newton by 4.448 Newton per pound and multiplying by the torsion wheel radius of 2 inches in the case of the 4 inch wheel for a torque of 4.047 in-lb. ,
- column 5 the converted data of angle of twist in radians becomes 0.393 radians per radian via 3 in. gage length divided by the radius of the glue stick (1/4 in.) and multiplied by 4.712 radians;
- column 6 the shear stress is computed from applied torque expressed in inch-pounds by multiplying the torque 4.047 in-lb. by the radius of the twisted sample (¼ inches) and dividing this quantity by the polar moment of inertia which is Pi (3.14157) times the diameter of the twisted member (1/2 in.) raised to fourth power and divided by 64. The units are pounds per square inch,
- column 7 incremental work is (329.760+256.480 lb./ sq.in.)/2*(0.393-0.262 radians/radian) = 38.369 in-lb/in^3,
- column 8 accumulated work is prior entry in column 8 (25.180 in-lb/in^3) plus 38.369 in-lb/in^3 or 71.942 in-lb/in^3,
- column 9 rate of loading via columns 4 and 3 or (4.047-3.147 in-lb)/(4.712-3.142 rad/rad) = 0.572 in-lb/rad/rad.

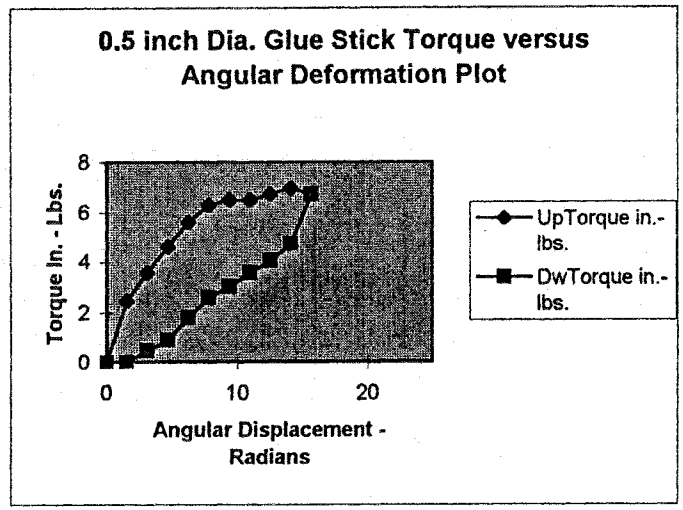
The total work done is 1815.348 in-lb/in^3 while the rate of loading after 450 degrees appears to oscillate between 0.572 and -0.572 in-lb/rad/rad.

2. For the recoverable features of the glue stick the 'level-off' torque in the vicinity the first values of 7.00 in-lb. as shown in Figure 2 was found. Figure 5 presents the data for the Second Test - UPLOAD and DWLOAD of the glue stick. In Figures 6, 7, 8, and 9 the are shown UPLOAD and DWLOAD torques, the UPLOAD and DWLOAD stresses, the UPLOAD and DWLOAD total torsional works and rate of loading curves, respectively. Figure 5 in columns 1, 2, and 3 presents the twist angle recorded as 0, 90, 180, 270,360, 450, etc. and the torsional loading and torsional unloading loads while in columns 4, 5, and 6 are found the total angle of twist in radians plus loading and unloading torques. Columns 7, 8, and 9 present the shear stain and shear stresses while columns 10, 11, 12 and 13 show incremental work and accumulated work. Columns 14 and 15 present the rate of loading computation.

Twist Ang. Degrees	UpForce Newtons	DwForce Newtons	Twist radians	UpTorque in.-lbs.	DwTorque in.-lbs.
0	0.00	0.00	0.000	0.000	0.000
90	5.50	0.00	1.571	2.473	0.000
180	8.00	1.00	3.142	3.597	0.450
270	10.25	2.00	4.712	4.609	0.899
360	12.50	4.00	6.283	5.621	1.799
450	14.00	5.75	7.854	6.295	2.585
540	14.50	6.75	9.425	6.520	3.035
630	14.50	8.00	10.996	6.520	3.597
720	15.00	9.00	12.566	6.745	4.047
810	15.50	10.50	14.137	6.969	4.721
900	15.00	15.00	15.708	6.745	6.745

Shr Strain Rad./rad.	UpShrStrs lbs./in.^2	DwShrStrs lb./in.^2	IncrWkUp lb in/In^3	TotWkUp lb in/In^3	IncrWkDw lb-in/in.^3	TotWkDw lb-in/in.^3	UpRate in-lb/rad	DwRate in-lb/rad
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.131	201.520	0.000	13.189	13.189	0.000	0.000	1539.499	0.000
0.262	293.120	36.640	32.374	45.564	2.398	2.398	699.772	279.909
0.393	375.560	73.280	43.765	89.329	7.194	9.592	629.795	279.909
0.524	458.000	146.560	54.556	143.885	14.388	23.981	629.795	559.818
0.654	512.960	210.680	63.549	207.434	23.381	47.362	419.863	489.841
0.785	531.280	247.320	68.345	275.779	29.976	77.338	139.954	279.909
0.916	531.280	293.120	69.544	345.324	35.372	112.710	0.000	349.886
1.047	549.600	329.760	70.743	416.067	40.767	153.477	139.954	279.909
1.178	567.920	384.720	73.141	489.209	46.763	200.240	139.954	419.863
1.309	549.600	549.600	73.141	562.350	61.151	261.391	-139.954	1259.590
				Percent Hystersis		53.518		

Figure 5. Second Test 0.5 in. All Purpose Glue Stick Recoverable Portion Data



igure 6. Second Test Load Plot

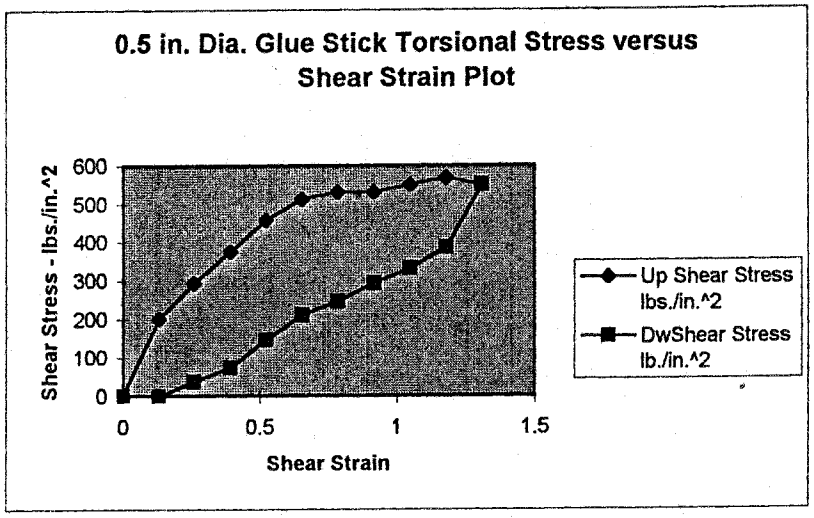


Figure 7. Second Test Shear Stress-Strain Plot

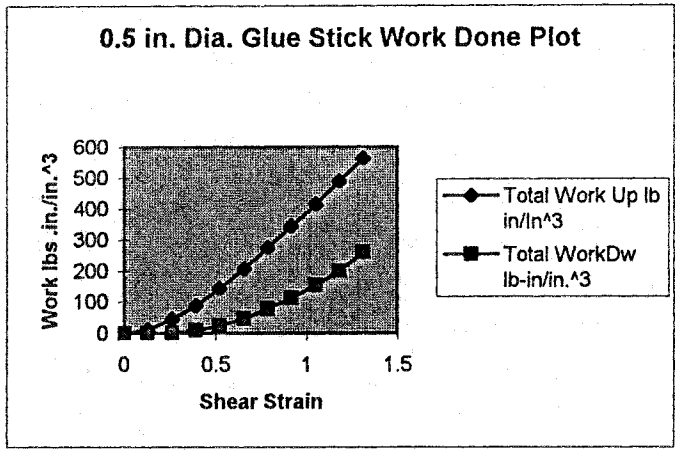


Figure 8. Second Test Work Plot

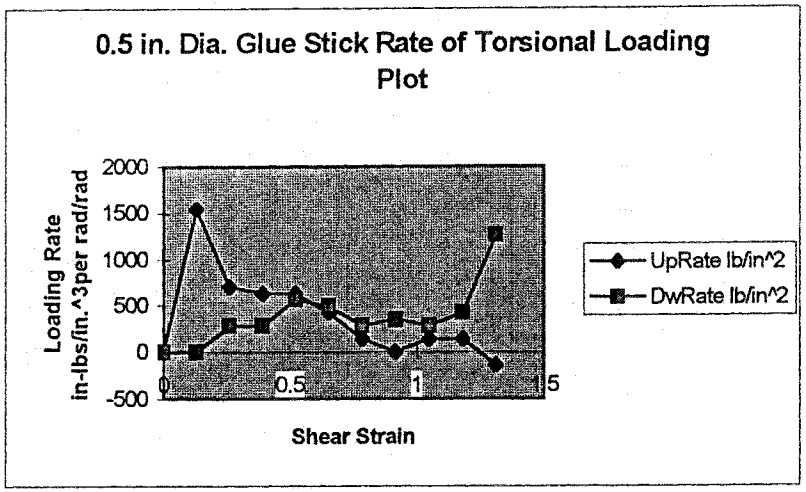


Figure 9. Second Test Loading Rate Plat Rate

To present the computations in figure 5, a hand calculation for the 270° angular displacement (0.393 Shr Strain) is given:

- upper columns 1 -3 are Figure 5 columns 1-3 and contain collected raw data
- column 4 270 degrees is (270/180)*3.14157 or 4.712 radians,
- column 5 the load of 10.25 Newtons is converted to a torque in inch-pounds by dividing the applied 10.25 Newton load recorded in Newtons by 4.448 Newtons per pound and multiplying by the torsion wheel radius of 2 inches in the case of the 4 inch wheel for a torque of 4.609 in-lbs. ,
- column 5 the load of 2.00 Newtons is converted to a torque in inch-pounds by dividing the applied 2.00 Newton load recorded in Newtons by 4.448 Newtons per pound and multiplying by the torsion wheel radius of 2 inches in the case of the 4 inch wheel for a torque of 0.899 in-lbs. ,
- lower column 1 is column 7 where the converted data of angle of twist in radians becomes 0.393 radians per radian via 3 in. gage length divided by the radius of the glue stick (1/4 in.) and multiplied by 4.712 radians;
- column 8 the Up shear stress is computed from applied torque expressed in inch-pounds by multiplying the torque 4.609 in-lb. by the radius of the twisted sample (¼ inches) and dividing this quantity by the polar moment of inertia which is Pi (3.14157) times the diameter of the twisted member (1/2 in.) raised to 4th power and divided by 64. The units are pounds per square inch,
- column 9 the Down shear stress is 73.280 lb/in.^2 following the procedure just presented, above,
- column 10 incremental Upwork is (375.560+293.120 lb./ sq. in.)/2*(0.393-0.262 radians/radian) = 43.765 in-lb/in^3,
- column 11 shows Totaled Upwork of 45.564 +43.765 in-ln/in.^3, while
- columns 12 and 13 repeat columns 10 and 11 for Down work with 7.196 and 9.592 in.lbs/in.^3, respectively,
- column 14 is Up rate of loading via columns 8 and 7 (the shear stress-strain data in place of the torque-angle of deformation data are used) is (375.560-293.120)/(0.393-0.262) for 629.795 lbs/in^2/rad/rad, and
- column 15 is the Down rate of loading for this case.

The total Up work done is 562.350 in-lb/in^3 while the total Down work recovered is 261.391 in-lb/in^3, which when subtracted and divided by the total Up work and multiplied by 100 gives 53.518 percent hystersis or energy lost while in the recovery of the twisted All Purpose Glue Stick. The rate of Up loading after 360 degrees appears below 400 lb/in^2 while the rate of loading varies in the down load review, but generally appears to reduce when the torque is removed.

Appendix - Torsion Tester Parts List:

The design and construction of a torsion tester is presented. Parts to make this unit include:

1. Flex-Angle™, of size 1 1/2 by 2 1/4 inches
   A. 4 pieces 18 inches long for uprights,
   B. 8 pieces 6 inch long pieces for the cages - four for each cage,
2. Two ½ inch diameter fine thread bolts 2 ½ inches long (1/2-20UNF-2Ax21/2 HX HD Bolt) - one for the disk via the Lazy Susan into the upper chuck and one for the lower moveable tail piece and lower chuck plus seven ½ inch bolt washers to be used as spacers,
3. Two ½ inch diameter Jacobs Multi-Craft® drill chucks,
4. Twelve 5/16 inch by 1 inch long bolts and nuts for the Flex angle and position indicator,
5. Four 4-40 round head 1/2 inch long machine screws and six washers to mount the Lazy Susan to the upper Flex angle cage and 4 number 5 round head wood screws to fasten the bearing to the lower chipboard disc
6. One 4 inch diameter Lazy Susan bearing made by EN-PAK®,
7. Two 1/2 inch thick chipboard disks each with a ½ inch diameter hole in the center and a circumferential 'V/U shaped' groove 1/8 inch deep - one 4 inch diameter and one 8 inch diameter are to be made,
8. Fifty feet of 50 pound test fish line,
9. A 20 Newton Ohaus® load scale to apply force,
10. Paper template for circular disk to mark 0,90,180, and 270 degrees of disk rotation and to be glue to the upper surface of lower chipboard disk,
11. An 8 inch long flat head piece of 1/8 inch diameter wire to be bent for rotary position indicator and mounted on the upper cage with a 7/16 bolt with nut,
12. One wood "2 x 3" x 5 ½ inch long with 17/32 inch diameter through hole in the center of the 3 x 5 ½ inch face,
13. One 10 in by 30 in by 1 inch mounting board, and
14. Two carrying handles (protruding window handle style.) plus 8 number 5 by ½ inch long mounting screws,
15. A 'U' Bolt to be made from a 13 inch long ¼ inch diameter threaded rod bent to have two 90 degree 4 inch long legs to place into the tester below the lower grip/cross-head to prevent the head from falling,
16. Four 7/16 one inch long machine screws with washers and nuts to fasten the tester via the lower cage to the mounting board.
17. A small c-clamp can be used to block rotation of the torsion wheel when placed on the disk that extends past the upper cage.

Appendix - View of the Torsion Tester:
Note the pointer to the top left of the lower wheel, the upper and lower cages, the moveable cross head, the 'U' bolt just below the cross head, and the Jacobs chuck key used to tighten the chuck jaws onto the glue stick.

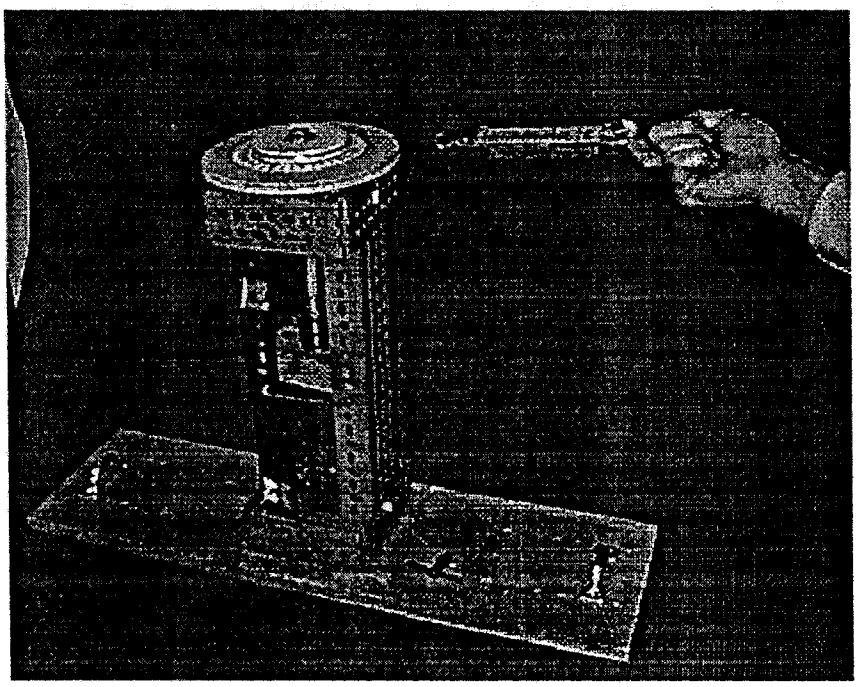


Figure 1A. Picture of Torsion Tester

Appendix - Assembly:
Obtain the parts. Assemble the upper and lower cages with one bolt in the corners of the narrow surface. Check that the pieces form a square. Join the four 18 inch pieces on the wide dimension with one and one-half inches overlap and fasten each unit of two pieces with one bolt in each end to cages. Fasten the lower wooden block via the ½ bolt, a washer, the block, a washer and the chuck. Make the disks. Mount the paper template on the top surface of the large disk. The upper bolt passes a washer, two disks, three washers into the upper chuck. To the upper cage fasten the lazy Susan bearing via the 4 small screws and washers. Prior to this the lazy Susan bearing is fastened to the lower disk with the four wood screws. Be sure the alignment is good. Mount the position pointer on the top cage. Wind the fish line around the upper disk groove - if the line is long friction will hold the line. Otherwise, drill two 1/8 inch diameter holes 3/8 inches apart near the edge groove and make a cut across the edge groove from one hole to the groove in the disk and tie the line down. Center the lower cage on the mounting board. Then mark and drill four holes in the mounting board aligned with the centers of the four sides of the lower cage. Countersink the hole from the bottom board surface and place the flat head machine screws into the board and add washers and bolts inside the cage.

Acknowledgments:
The author is appreciative of the assistance provided by Mrs. Karplus throughout the construction, assessment and conduction of early test with the torsional test apparatus.

MAKING THE JUMP FROM ROTE LEARNING TO APPLICATION IN 50 MINUTES

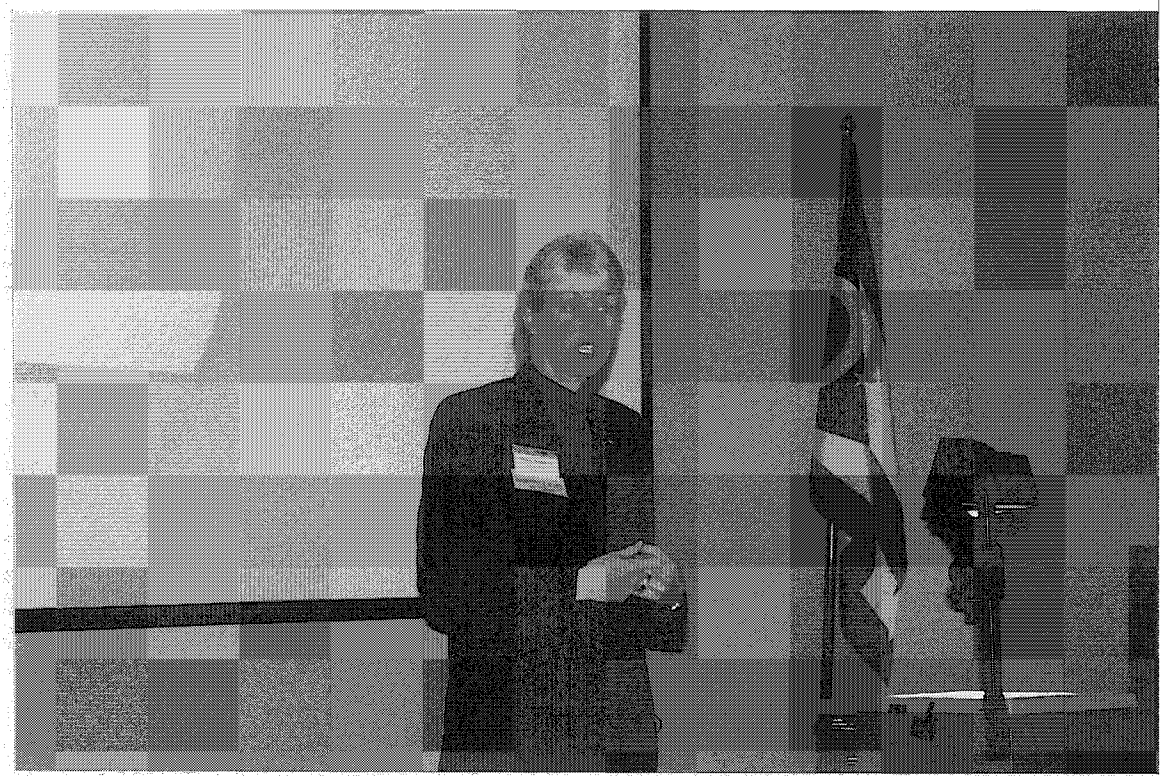
Donna C. S. Summers

University of Dayton
Industrial Engineering Technology
300 College Park Drive
Dayton, Ohio 45469-0249

Telephone: 937-229-2974
e-mail dsummers@engr.udayton.edu

Biography:

Dr. Donna C.S. Summers teaches in the Industrial Engineering Technology program at the University of Dayton. She earned her Ph.D. at the University of Cincinnati, where her major areas of study included Quality Assurance and Human Factors. Dr. Summers consulting work has focused on problem-solving through the application of quality assurance techniques. Her text, Quality, contains numerous case studies based on her consulting work.



Making the Jump From Rote Learning to Application in 50 Minutes

Donna Summers, Ph.D.
Industrial Engineering Technology
University of Dayton

Abstract:

In a traditional Statistical Process Control (SPC) course experimentation is limited due to the fifty minute time span of a typical structured course. Still, students need to gain knowledge of the practical application of the SPC tools in a business setting. End-of-chapter problems rarely provide insights into the complexities of solving an actual industrial dilemma. Without this knowledge, how will students learn which tools and techniques to apply to what situations? This presentation discusses the use of case studies in a traditional fifty minute class in order to help students make the leap from rote learning to application of techniques.

Key Words:

Case study, statistical process control, data gathering, technique selection, technique application, data interpretation.

Prerequisite Knowledge:

An understanding of computers and familiarity with installing commercial software on PC's. A basic understanding of probability and statistics.

Objectives:

To use Case Studies to:

- -create an understanding of the complexities of problem-solving in a business setting.
- -encourage the use of statistical data when making decisions.
- -enhance student's understanding of the importance of interpreting statistical data when making decisions.

Equipment and Materials:

A case study.
Visual aids associated with the case (parts, drawings, products, etc.).
Access to computers and statistical process control software.

Introduction:

Case studies based on real-life situations provide students with an understanding of the knowledge and effort necessary to solve business problems. In a traditional Statistical Process Control class, students are exposed to the techniques associated with problem-solving through lectures and related end-of-chapter problems. Though this provides students with a working knowledge of SPC tools and techniques, it does not necessarily prepare them with the knowledge necessary to know when to apply what techniques when a particular situation arises on-the-job. This lack of applications knowledge may lead to a more shoot-from-the-hip, feelings-styled approach to problem-solving, rather than an organized approach involving analyzing data related to the problem.

The use of case studies in a traditional classroom brings students insight into the complexities of real-world quality assurance.

Procedure:

Preparing a Case

Case studies enhance students' understanding of the complexities of problem-solving in an business setting. The key to the successful application of cases in a SPC course is the availability of abundant real data. Cases can come from a variety of sources including past consulting experiences or any day-to-day product or service that is experiencing difficulties. The writer of the case must have access to industrial data or the ability to generate such data. Cases are difficult to construct using artificially generated data. And unlike real data, artificial data, doesn't give the student insight into the complexities of real-world problem-solving. Instead, the tidy answers artificial data create may inhibit student learning by causing them to assume an answer is always readily available. Real data is slippery and must be analyzed to determine what it is trying to tell us. This analysis is what generates student learning and underscores the importance of interpreting statistical information when making decisions.

Several cases should be used throughout the term. They should cover a wide variety of industries including manufacturing, chemical processing, electronics, computers, packaging, hospitals and other service industries, as well as government applications like the Post Office or the IRS. The cases should require the gathering, analysis and interpretation of data, as well as background information related to the problem. This ensures that the students learn that quality assurance issues do not magically appear, instead, they are caused by the decisions made by those associated with the manufacture of a particular product or the provision of a service. Some of the cases used should be open-ended, others should have a more narrow focus with specific answers. This will encourage the student to think about the complexities of life in business.

Because problem-solving in industry requires the application of a variety of techniques, many cases may merge information and techniques from several chapters. For example, in a study related to a bracket creating difficulties during an assembly process, the case

may use flow charts to describe the assembly process, Pareto diagrams to determine the most likely area to investigate, a cause-and-effect diagram to isolate the potential causes, and histograms or control charts to analyze data related the bracket hole alignment that has been identified as the root cause of the problem.

Another challenge facing the writers and users of case studies is the need to convert information and data associated with a real-world problem into a usable structure for learning. Ease this process by focusing on formulating the case around proposed class discussions of crucial formulas or ideas. Provide sufficient background information to enable the students to understand the problem at its inception. As the case develops, additional information can lead the student through the problem-solving process.

Using Cases in the Classroom

Case studies encourage the use of statistical data in decision-making. Users of case studies need to be aware of several aspects concerning cases that are critical when using them in a classroom setting.

Most importantly, cases should be well integrated with the material covered in the chapter. For SPC, the focus of these cases should be on the analysis and use of quality assurance techniques when solving complex problems.

Case studies are used most effectively when the students work on the cases in parallel with class discussions of pertinent material. Due to their complex nature, work on case studies often extends from one class to another, just like problem analysis in business extends over a several day period of time. If the case is structured to mimic a business environment, then the information presented in the case, as well as the solution to the case will extend over several class periods. This approach enhances student learning because it gives them time to absorb the information in class, apply relevant classroom information to the case, and discuss the evolving results in class. This parallel problem-solving, question and answer format brings the material to life and creates a necessity for understanding the material as it is presented, not just immediately before the exam for use in solving simpler problems.

The use of computers and commercial software will enable the students to analyze and interpret realistic charts created with a significant amount of data. This is crucial in order to add depth and complexity to the problem-solving experience. The use of computers also enables students to complete the problem-solving exercises without becoming bogged down in calculations. For the customary SPC class, software which creates histograms, Pareto diagrams, X-bar, R, p, u, and c charts should be sufficient for most case studies.

Comments:

The use of cases in a fifty minute class enlivens lectures by adding discussion elements concerning real world products and services. Using cases in conjunction with traditional

lectures and homework problems requires time for in-class discussion of the cases. Class discussion of material should reference the case in order to make it an integral part of the course rather than just another assignment. On the surface, it may appear that allocating time for in-class discussion of the case detracts from needed lecture time. On the contrary, discussions focused on the cases tend to encourage student learning and generates an answer to "why do we have to know this?" An enhanced understanding of the applicability of the information increases student interest in the material thus improving the accumulation and retention of information.

References:

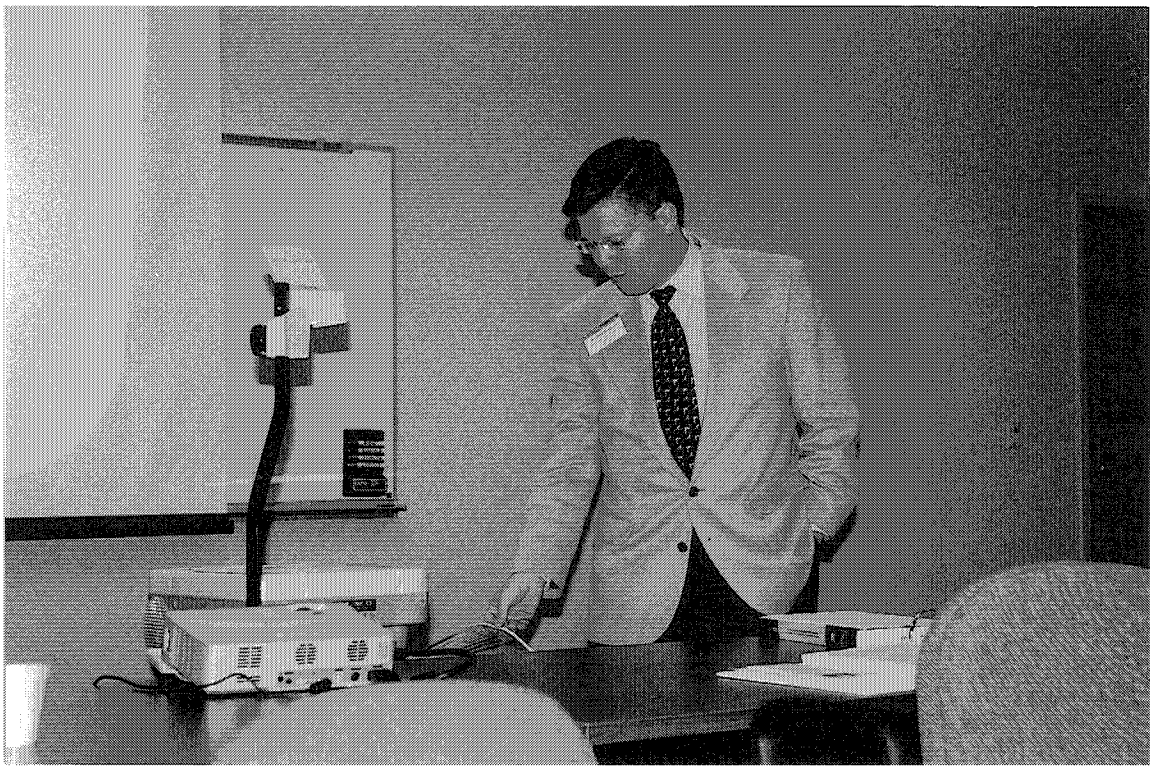
Summers, D. Quality, 2nd ed., Prentice Hall: Upper Saddle River, NJ (2000).
TQT Handbook, PQ Systems, Dayton, Ohio (1996)

DEVELOPMENT OF COMPOSITE MATERIALS MANUFACTURING AND EXPERIMENTAL EVALUATION FACILITIES FOR UNDERGRADUATE ENGINEERING STUDENTS

Ronald B. Bucinell

Union College
Department of Mechanical Engineering
Schenectady, New York 12308

518-388-6023
bucinelr@union.edu



Ronald B. Bucinell

Development of Composite Materials Manufacturing and Experimental Evaluation Facilities for Undergraduate Engineering Students

Ronald B. Bucinell, Ph.D., P.E.
Union College
Department of Mechanical Engineering
Schenectady, NY 12308

National Educator's Workshop – 2000
October 29, 2000 – November 1, 2000

In the last quarter of the 20th century, the use of advanced composite materials grew rapidly in aerospace, hydrospace, infrastructure, automotive, and sporting goods markets. The macroscopically heterogeneous and anisotropic nature of these materials complicates their behavior and performance. Courses covering composite material behavior and design have traditionally been offered as electives in the senior year or more commonly in graduate programs. As a result few engineering students that are graduating with bachelor degrees in engineering are able to optimize the performance of composite materials through design.

With the help of the National Science Foundations ILI program, Union College has developed manufacturing and experimental evaluation laboratories dedicated to introducing composite materials to undergraduate students. Undergraduate students at Union College now encounter composite materials as early as their sophomore year in their material science and mechanics of materials courses. In the junior and senior years, students can take introductory courses to composite materials and composite material manufacturing. These facilities are also made available to students for their senior capstone project.

It is not practical to infer that a graduate level understanding of composite behavior can be provided to undergraduate students. It is reasonable to provide undergraduates exposure to the unique behavior of composite material and give them an introduction to these materials that will aid them in the design of structures that utilize this class of materials.

Biographical Summary For

Ronald B. Bucinell, Ph.D., P.E.

Dr. Bucinell is an Assistant Professor of Mechanical Engineering at Union College. Since joining Union College in September of 1993, he has taught courses and laboratories in engineering mechanics and design. His other responsibilities include undergraduate academic advising, senior design project supervision, undergraduate research supervision, and graduate research supervision. Dr. Bucinell is currently advisor to the International Virtual Design Studio project that is currently being conducted in conjunction with the Middle East Technical University in Ankara, Turkey and ESIGELEC in Rouen, France. He is working to expand this program to several other international universities and corporations. Dr. Bucinell is also advisor to the Mini-Baja and Formula SAE racing teams at Union College. He has taken a leadership role in developing undergraduate laboratories, the new undergraduate curriculum, and revisions to the graduate program for the Mechanical Engineering Department at Union College. He is the director of the engineering mechanics and composite materials manufacturing laboratories at Union College.

Dr. Bucinell's research areas include mechanics of composite structures, test method development, and design. He has been awarded NASA Summer Fellowships in 1994, 1995, 1996, and 1997. He currently is working on grants from NASA, the U.S. Navy, U.S. Airforce, and U.S. Army. He is also working with several small businesses to develop their composite materials technology. Dr. Bucinell is also working with the New York State Department of Transportation on introducing composite materials into the infrastructure of New York State.

Prior to joining Union College, Dr. Bucinell was employed by Materials Sciences Corporation in Philadelphia, Pennsylvania as a research engineer for four years. His responsibilities included the development of thermal-mechanical models to predict the response of composite materials and structures, test method development, and material processing models. Prior to this Dr. Bucinell was employed by Hercules Aerospace Corporation in Salt Lake City, UT, for three years. While at Hercules he was actively engaged in research activities that focused on the application of advanced materials to rocket motors. Some of the rocket motor programs that Dr. Bucinell has participated on include Titan IV, Delta II, SRAM, Small ICBM, Trident, Peace Keeper (MX), Space Shuttle Solid Rocket Motors, and many others. Dr. Bucinell was also employed by Boeing Aerospace in Seattle, Washington and the Dyna East Corporation in Philadelphia, PA. In 1990 Dr. Bucinell co-founded the company Innotech (518/783-0800) that provides a variety of engineering design and analysis services to corporate and government clients.

Dr. Bucinell holds the degrees of B.S. in Mechanical Engineering from the Rochester Institute of Technology; M.S. in Mechanical Engineering and Applied Mechanics from Drexel University; and a Ph.D. from Drexel University. From 1987 to 1990, he held the position of Adjunct Assistant Professor of Mechanical Engineering at the University of Utah and from 1992

to 1994 held the position of Adjunct Assistant professor of Mechanical Engineering at Temple University.

Dr. Bucinell is a licensed Professional Engineer in the State of New York. He is currently a member of the American Society of Mechanical Engineers (ASME), American Society for Testing and Materials (ASTM), Society for Experimental Mechanics (SEM), American Society for Engineering Education, and Sigma Xi (Honorary Research Society). He is the Co-Editor of the Journal of Composite Technology and Research. He is chairman of the ASTM D30 Ring and Filament Wound Test Methods Task Group (D30.04.05) and Chairman of the ASTM D30 Research and Mechanics Subcommittee (D30.02). Dr. Bucinell was the chairman of the ASTM VII Symposium on Fatigue and Fracture to be held in St. Louis on 5-8 May 1997. Dr. Bucinell is listed in Marquis Who's Who in Engineering, Marquis Who's Who in Finance and Industry, and in Marquis Who's Who in the World. He has authored many papers in the field of composite materials, has presented his work at technical symposia, and has been invited to speak at several government installations.

Dr. Bucinell's civic activities include the introduction of a NSF/Smithsonian hands-on-science program to the Elmer Avenue Elementary School, in Schenectady, NY, in the 1st and 3rd grade during the 1994-95 school year. This program was so successful that in 1995 a Goals 2000 grant was awarded to the Schenectady School District to introduce this hands-on science program in grades 1 through 4 in five of the Schenectady elementary schools. Additionally in 1995, Dr. Bucinell was awarded a grant from Sigma Xi to pilot a hands-on science program in the 5th grade of the Elmer Avenue Elementary School. Dr. Bucinell is a member of the local school district Parent Teacher Organization and has served as a member of the Local School Shared Decision Making Team. He has also served on school district committees to bring technology into k-12 education. He is also a Cub Scout den leader and Boy Scout advancement chairman. He is currently a Boy Scout merit badge counselor for space exploration, engineering, scholarship, drafting, astronomy, climbing, and personal fittness. He also coaches little league baseball, youth hockey, and youth football.

NANOTECHNOLOGY EDUCATION: EXPLORING A COMPACT DISK STAMPER

B. L. Ramakrishna

Center for Solid State Science and
Department of Plant Biology
Arizona State University
Tempe, Arizona 85287-1704
e-mail bramakrishna@asu.edu

Eddie W. Ong
and
Andrew Chizmeshya

Center for Solid State Science
Arizona State University
Tempe, Arizona 85287-1704

Telephone: 480-965-6560

Jeremy Rowe

Information Technology
Arizona State University
Tempe, Arizona 85287-0101

Biography:

B.L. Ramakrishna is an Associate Professor in the department of Plant Biology and Director of Education and Outreach programs in the Center for Solid State Science. He received his Ph.D. from Indian Institute of Technology, Madras, India. His research interest is in the area of nanoscale studies of Biomineralization, where problems lie at the crossroads of Biology and Materials Science. He is committed to the integration of research frontiers into the undergraduate curriculum.

Eddie W. Ong is a research scientist at the Center for Solid State Science currently working on the IN-VSEE project and manages the multi-user Scanning Probe Microscopy (SPM) Facility at Arizona State University (ASU). He received his Ph.D. in Solid State/ Inorganic Chemistry from ASU. He then worked as a Postdoctoral Fellow at Los Alamos National Laboratory and has also taught at Northern New Mexico Community College and Maricopa Community Colleges in Arizona. He is experienced in the use of multiple techniques for the characterization of materials and is involved with the development of SPM over the Internet as an education and outreach resource for high school and undergraduate students.

Jeremy Rowe serves as an academic professional for Information Technology at Arizona State University. He received his Doctorate in Educational Leadership and Policy Studies and Masters in Educational Technology and Audiovisual Education from Arizona State University. He has been involved in planning for preservation of non-print media and in policy issues related to copyright, licensing, and ownership of multimedia materials.

Andrew Chizmeshya is a condensed matter physicist in the Center for Solid State Science at Arizona State University (ASU), and the director of the Goldwater Materials Visualization Facility. He received his Ph.D. Condensed Matter Theory from Queen's University at Kingston, Canada. Dr. Chizmeshya is involved in the development of K-12 science education materials, including the implementation, testing and deployment of remote access educational resources.

B. L. Ramakrishna

Nanotechnology Education: Exploring a Compact Disk Stamper

B.L. Ramakrishna[1,2], Eddie W. Ong[1], Jeremy Rowe[3] and Andrew Chizmeshya[1]

[1]Center for Solid State Science, Arizona State University, Tempe, AZ 85287-1704
[2]Department of Plant Biology, Arizona State University, Tempe, AZ 85287-1601
[3]Information Technology, Arizona State University, Tempe, AZ 85287-0101

Abstract:

The integration of nano-science and technology concepts into the curricula of upper-division high school and lower-division college levels, requires innovative educational approaches that will help students understand the structures at the nanoscale and its correlation to the properties of matter at the macro-, micro- and nanoscale. Important vehicles for training these students include the integration of analytical instrumentation with materials education, and employment of advanced telecommunication technology to deliver an interactive and discovery-based educational experience.

The Interactive Nano-Visualization for Science and Engineering Education (IN-VSEE, http://invsee.asu.edu) project has created a consortium of university and industry researchers, community college and high school faculty and museum educators, led by Arizona State University (ASU), with a common vision of building an interactive World Wide Web (WWW) site to develop a new educational thrust. This NSF-funded project has developed a remotely operable scanning probe microscope (SPM), a visualization gallery of images, and a number of educational modules designed around materials themes.

The important goals of the IN-VSEE project are to (1) educate students in the principles, execution, interpretation, and rational design of experiments.; (2) increase student understanding of structure, composition, and properties of materials across size scales with examples that cut across traditional disciplinary barriers and (3) to prepare the future workforce for the upcoming nanotechnology revolution.

This paper describes investigations of a CD stamper to demonstrate how of investigating a material by multiple techniques can give a comprehensive and self-consistent knowledge of its structure and composition at the macro-, micro- and the nano-scale. The choice of the familiar CD brings relevance to materials science and engineering education content. The ability to access sophisticated instrumentation remotely via the Internet facilitates the building of a "laboratory without walls" and brings a new meaning to hands-on experience

The use of multiple analytical instruments such as Optical Microscopy, Scanning Electron Microscopy (SEM), SPM, Energy Dispersive X-Ray Spectroscopy (EDX), Auger Electron Spectroscopy (AES) and Rutherford Backscattering (RBS) in understanding the structural and materials aspects of a compact disk stamper will be illustrated. Remote experimentation over the World Wide Web using Scanning Probe Microscopy (SPM) and Rutherford Backscattering (RBS) will be demonstrated.

Key Words: IN-VSEE, Interactive Nano-Visualization for Science and Engineering Education, nanoscience, nano-engineering, nanotechnology, Compact Disk, remote experimentation, Scanning Probe Microscopy (SPM), Scanning Electron Microscopy (SEM), Optical Microscopy, X-ray diffraction, Energy Dispersive X-Ray Spectroscopy (EDX), and Rutherford Backscattering (RBS).

Prerequisite Knowledge:
Introductory information on the size and scale of various objects and the use of microscopy to explore these objects can be found on an IN-VSEE module "Size and Scale" at

http://invsee.asu.edu/nmodules/sizescalemod/

Information about the operating principles of a Scanning Probe Microscope can be found on an IN-VSEE module "Theory and Simulation of SPM" at

http://invsee.asu.edu/nmodules/spmmod/

Information on the formatting and manufacturing of optical storage media can be found on an IN-VSEE module "Information Storage Media – the Information Age is Here" at

http://invsee.asu.edu/nmodules/ismmod/

Summary information on the working principles, advantages, and limitations of a number of analytical instrumentation are illustrated in the schematics shown in Figure B. Additional information can be found on Charles Evans & Associate's web site on the following pages

Working principles: http://www.cea.com/whatis.htm
Technical limits: http://www.cea.com/table.htm

Objectives:
Determine the physical dimensions of the data bits.
Determine the chemical composition of the sample.
Relate the data capacity of the CD to the dimensions of the data.
Relate the optical properties for e.g. Iridescence of the CD to the feature sizes.
Relate the measurements at the micro and the nano scale to the physics of the CD.

Equipment and Materials:
Instrumentation
Analytical instruments expand, beyond the capabilities of the human senses, our knowledge of materials systems. The equipment below was used for exploring the compositional and topographical nature of the CD stamper. In this paper we are illustrating the utility of these various techniques and how they can be used to get a comprehensive examination of the sample. However, if some or all of these facilities are not available close at hand, one could utilize experimental resources around the country to obtain data on samples. It is possible to obtain the data from various image galleries over the web such as from e.g. http://invsee.asu.edu. It is also possible to access some of these sophisticated instruments via the Internet.

Analytical Technique	**Instrumentation / Model**
Optical Microscopy	
Scanning Probe Microscopy (SPM)	Digital Instruments Nanoscope III™ AFM Thermomicroscopes Explorer™ AFM
Scanning Electron Microscope and (SEM)	JEOL JSM-840

Energy Dispersive X-Ray Spectroscopy (EDX)	Same as above
Rutherford Backscattering (RBS)	Built in-house, Ibeam Facility
Auger Electron Spectroscopy (AES)	Physical Electronics SAM 590

Information on the technical specifications and capabilities of the instruments at ASU that was used for this study can be found at:

http://gmsl.eas.asu.edu/gmvf

IN-VSEE's Remote SPM instrument can be accessed through the IN-VSEE web site at:

http://invsee.asu.edu

under the heading of "SPM Live!"

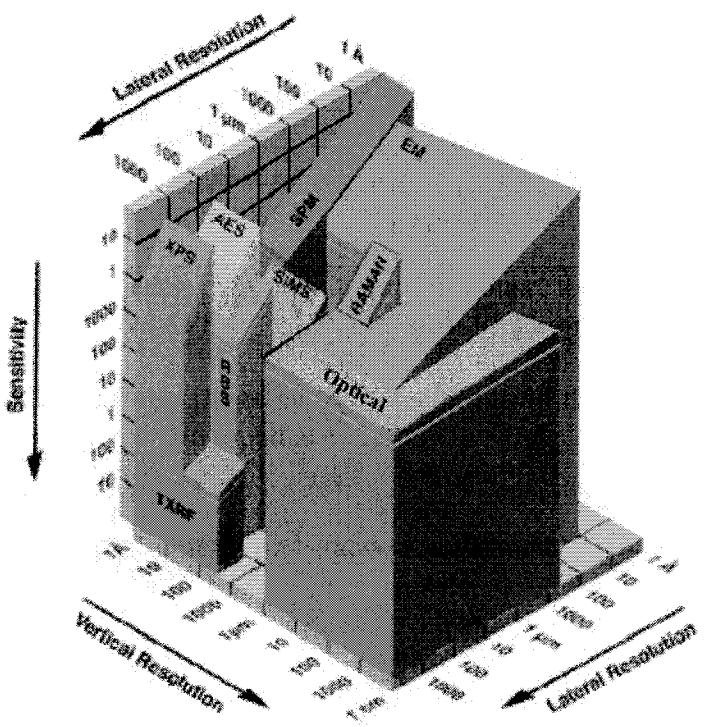


Figure A. Spatial resolution and relative sensitivity of some commonly used analytical instruments.

The picture above (Figure A) schematically shows the spatial resolutions and sensitivities of a number of analytical instruments, which measure topography, optical properties, chemical composition, electronic structure, etc. Summaries about the operating principles of several surface analytical techniques can be found in a reference by Somarjai [1]. Schematics showing illustrating the operating principles of advanced surface analytical instrumentation for chemical analyses is shown in Figure B below.

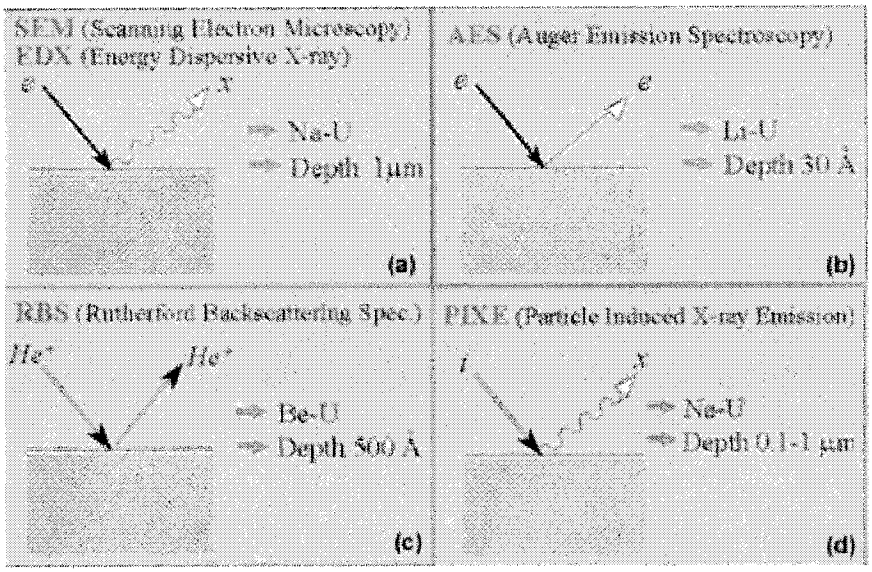


Figure B. The operating principles of some of the advanced analytical techniques used to determine the chemical composition of the CD stamper surface: (a) EDX, (b) AES, (c) RBS, and (d) PIXE. The elements that the techniques can detect and the surface penetration depths are shown. (Adapted from reference 2).

Material

Compact Disk (CD/DVD) and Compact Disk stamper samples can be procured from:
Maxwell Production, LLC
8521 E. Princess Drive, Scottsdale AZ 85255
telephone: (480) 609-9555.

Introduction:

Compact Disks

Optical media systems read the differences in laser light reflected from a series of holes or pits on the surface to represent the 0s and 1s of binary data. The use of phase shifts to detect minor changes in material surface is based on a technique developed in 1934 by Nobel Prize winner F. Zernike.

The first popular use of optical storage began in the 1970's with release of the Pioneer® video laser disk. The disks were about 30 cm in diameter. Despite slow public acceptance of the videodisk, soon the 13 cm audio CD-ROM was released. The audio CD was accepted almost immediately and soon replaced the LP record as the most popular media for distribution of music. The use of CD-ROM for data storage followed soon after.

CD-ROM store data in patterns of small pits arranged in over many thousands of tracks across the surface of the disk. CD-ROM drives use a laser from below the disk to read the data from the disk. The presence of a passing pit, or space, effects the reflection of the laser from the surface of the CD-ROM. The changes are captured by the lens, converted into electrical signals and translated into data. The data can represent audio, video or computer readable files.

The natural curiosity, familiarity with CDs, as well as the richness of experimental tools that can be brought to bear makes a Compact Disk stamper sample an excellent candidate for experimental exploration. The investigation of a CD sample provides a valuable and attractive means to illustrate some basic principles of physics. It allows one to bring to the fore some of the materials and engineering issues. The Common questions asked by students include:

What causes the rainbow effect of light shining on a CD or CD stamper?
What kinds of materials are used to make CD and its stamper master and what criteria determined the choice of material?
How does the surface of a CD stamper look topographically and chemically?
How big are the data bits on a CD? Are all of the data bits the same size?
How can we estimate how much data can be stored on a CD?
How is the data read?
How do the size of the data bits and track separation relate to the wavelength of the laser used for reading the data on a CD?

Procedure:

Sample preparation

Obtain a CD stamper sample and cut out several (5-6) pieces that are roughly 1cm X 1cm using a scissors or a pair of tin snippers. Avoid leaving fingerprints on the shiny surface of the sample with your hand. Place the samples in a beaker containing acetone and place in a sonicator to clean any dust, grease and other contaminants for 10 seconds. Repeat the sonication with trichloroethylene (TCE) in the beaker in place of the acetone for another 10 seconds. Pour out the solvent and allow the samples to dry for 4-5 hours. Consult your instrument operator for instructions on mounting the sample and running the instrument.

Results:

The CD stamper sample was investigated by several techniques that allows one to get a comprehensive picture at the macro-, micro- to the nano- scale. In the following paragraphs the results from the various tools are described. The sample was first inspected visually with our eyes and then with a photographic camera. Then the optical microscope was employed to observe features that were not visible to the human eye but this yields only 2-D information. To extend our sense of touch, a SPM was used to "feel" the surface to determine the 3-dimensional aspects of the features. A SEM in combination with EDX was then used to get information about the chemical composition. More refined compositional analysis was accomplished with AES which provides information about lighter elements as well as depth profiling. RBS and PIXE were employed to determine whether the elements exist in more than one compound on the surface.

Eye

A macroscopic visual inspection of a CD or a CD stamper shows a shiny reflective disk. A typical view of a CD is shown in Figure C. The samples display a rainbow-color reflection of light when the object is tilted at different angles relative to the eye. What is

causing this play of the color? Is this due to the chemical or structural characteristics of the object's surface?

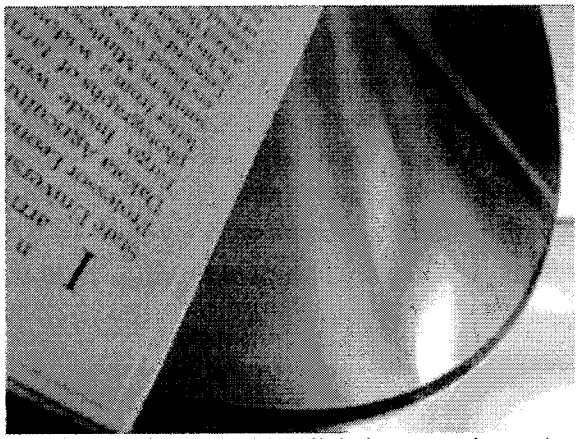


Figure C. Macroscopic image of a CD obtained with a digital camera shows the rainbow of colors on the CD surface, seen above as different shades of gray.

Optical Microscopy

Closer inspection with an optical microscope, utilizing the interaction of visible light with the surface is illustrated by the image of the CD stamper shown below in Figure D. There are topographical features on the surface of uniform width and in 3 different lengths. There arranged into lines, known as tracks, separated from each other at a uniform spacing. What is the topographical nature of these features? Are they flat, depressions, or protrusions on the surface? Non-uniformity in the color of the surface is observed. What is causing these different colors? Are these regions of corrosion? Are these due to thin coating of contaminants on the surface?

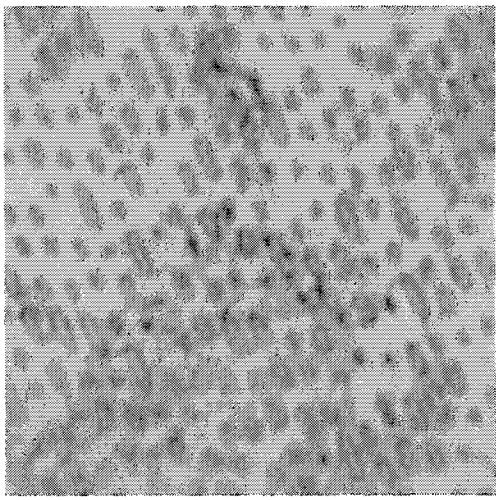


Figure D. 30μm x 30μm area of CD stamper surface observed by optical microscope. The non-uniform colors may be due to surface contaminants or corrosion.

SPM

A three-dimensional examination of a CD or CD stamper surface by a scanning probe microscope, utilizing a very probe, shows that the features on the surface are not flat

(Figure E). The image obtained from this instrument is shown below where the height of the feature is color-coded, lightest color is highest. On a CD these features, known as steps, are depressions while on a CD stamper these features are protrusions. The height of the protrusions is about 200 nm. The width of these features is around 0.75μm. The lengths measure about 1μm, 2 μm, and 3 μm for the short, medium, and long features, respectively. A distance of 1.5 μm separates one track from the next.

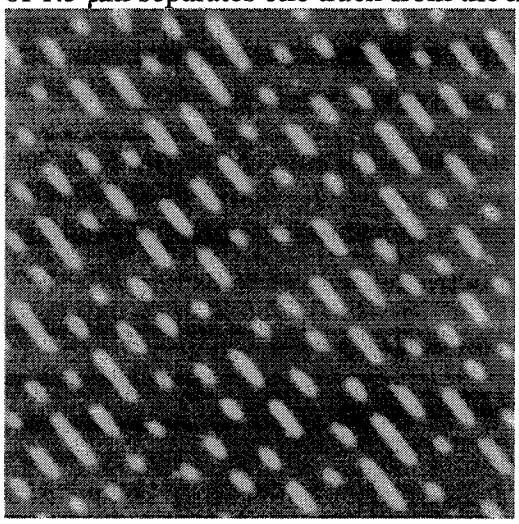


Figure E. 30 μm x 30 μm scan of CD stamper surface by SPM to obtain 3-D topographic information. The brighter areas are higher off the surface.

SEM and EDX

The CD stamper was further examined using a scanning electron microscope. The images obtained showed similar features to those found by SPM. The dimensions of the surface features as measured by SEM agree with those reported by the SPM. However, height information cannot be obtained from the SEM data. This instrument, when fitted with an EDX capability, has the advantage of being able to pinpoint a location on the surface and obtain information about the chemical composition of the sample there. Figure F shows the SEM image of the CD stamper surface. Areas that hold a higher charge are brighter in color.

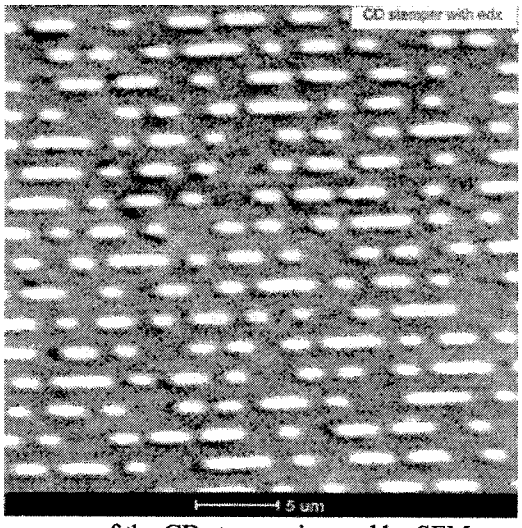


Figure F. A 30 μm x 30 μm scan area of the CD stamper imaged by SEM.

Several locations on the surface of the CD stamper were probed by the EDX attachment of the SEM to determine the stamper's chemical composition. A typical EDX spectrum of the surface is shown below (Figure G). This spectroscopy showed that the stamper was made from nickel. Is this sample made entirely from nickel? From this analysis we know that no other elements with an atomic number higher than sodium is present, besides nickel. However, we can neither confirm nor deny the presence of elements lighter than sodium on the surface because of detector limitations of our instrument.

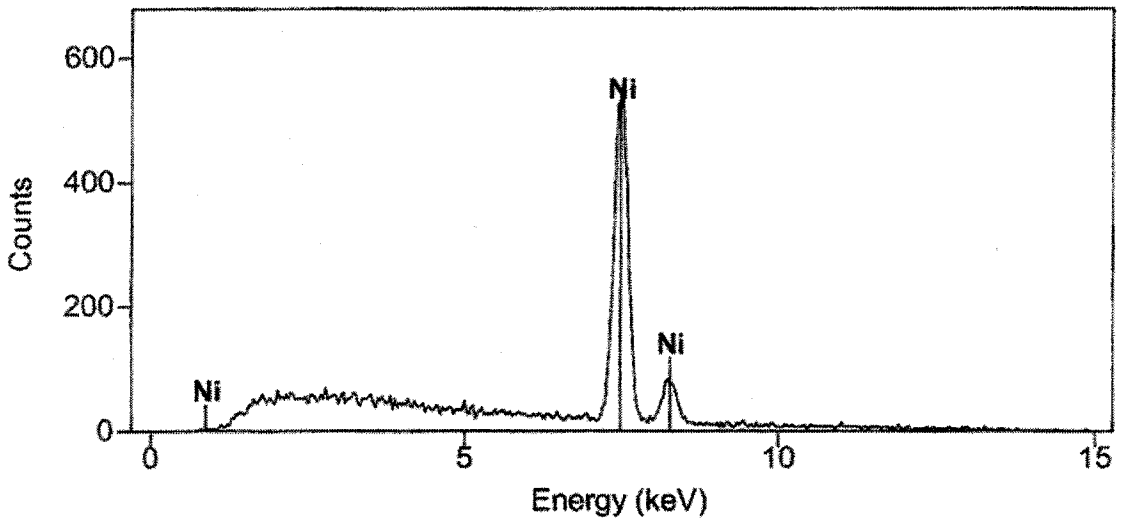


Figure G. A typical EDX spectrum of the CD stamper surface. It is composed mostly of nickel.

AES

A survey of the CD stamper surface with Auger electron spectroscopy, after the SEM/EDX experiments were performed, revealed the presence of carbon, oxygen, and traces of nitrogen besides nickel. An AES spectrum of surface is shown below (Figure H). Does this composition represent the chemical makeup of the object?

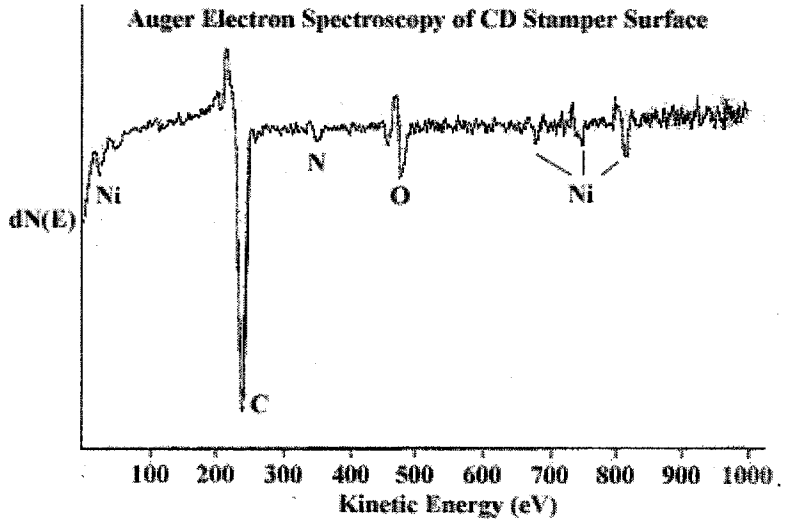


Figure H. An AES spectrum of the CD stamper surface showing the presence of nickel, carbon, oxygen and nitrogen.

The penetration depth of the AES analysis is rather shallow. Since our AES instrument is outfitted with an ion gun that can dig through the sample surface with argon ions at 20 nm/min, we performed a compositional depth profile. The elemental composition changed with the depth from the surface. Figure I below shows the atom percent of each element as a function of depth.

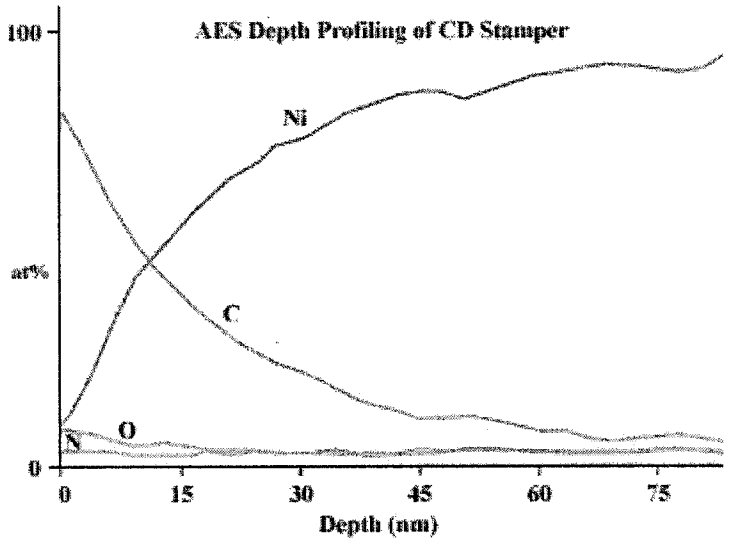


Figure I. AES depth profiling of the CD stamper shows a change of composition with depth from the surface.

Carbon and nickel dominate the surface. The negligible amounts of oxygen present suggests that very little of the nickel is in the form of oxides. The large quantity of carbon on the surface may be an organic contaminant or polymer there. The interior of the CD stamper is composed of nickel.

RBS and PIXE

Rutherford Backscattering analyses was performed on the surface of the CD stamper to determine if the chemical elements present exist in more than one form (i.e., contained in different compounds. Helium ions of several energies were used to study the depth dependence of the elements. Nickel was found to exist predominantly as metallic nickel. Carbon was also detected and found to decrease with depth from the surface, supporting the AES depth profiling results. Particle Induced X-ray Emission spectroscopy found traces of iron along with the metallic nickel. These findings are shown by Figures J and K, respectively.

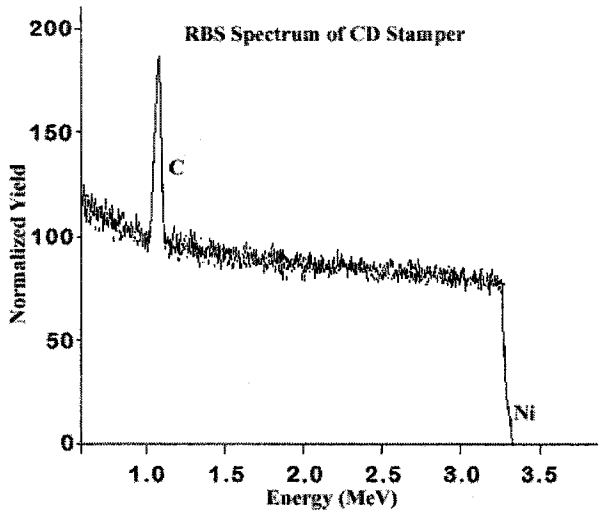


Figure J. An RBS spectrum of the CD stamper surface showing a single species of nickel and the presence of carbon. The intensity of the carbon peak decreased with depth.

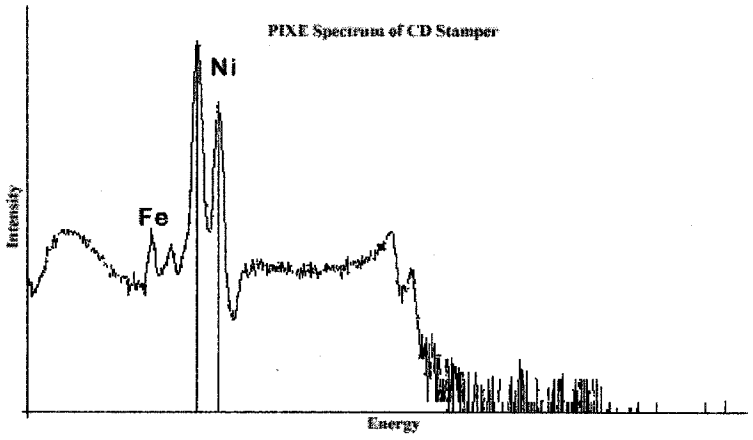


Figure K. PIXE spectrum of CD stamper surface shows the presence of nickel and traces of iron. The other techniques did not find the presence of iron.

X-ray Diffraction

The analytical techniques discussed above do not tell us if the nickel exists in a crystalline or amorphous form and how the grains of nickel composing the CD stamper are oriented. X-ray Diffraction experiments, using X-ray radiation produced by a copper anode (Cu Kα; wavelength = 1.5418 Angstroms), were performed to answer these questions. The resultant diffraction pattern, shown in Figure L, is consistent with the material being crystalline metallic nickel with its atoms arranged within a face-centered cubic unit cell with sides measuring 0.3524 nm (3.524 Angstroms). This pattern, however, does not match the ideal X-ray "fingerprint" of a metallic nickel sample that has its grains randomly oriented. Instead it shows that the crystalline grains of nickel were preferentially oriented with its (100) crystalline axis perpendicular to the CD stamper surface as evidenced by the intense (200) diffraction peak. If etched, the surface may exhibit a large number of crystalline grains with right-angled boundaries. The

growth behavior of the nickel grains may have been affected by the methods used to fabricate the CD stamper.

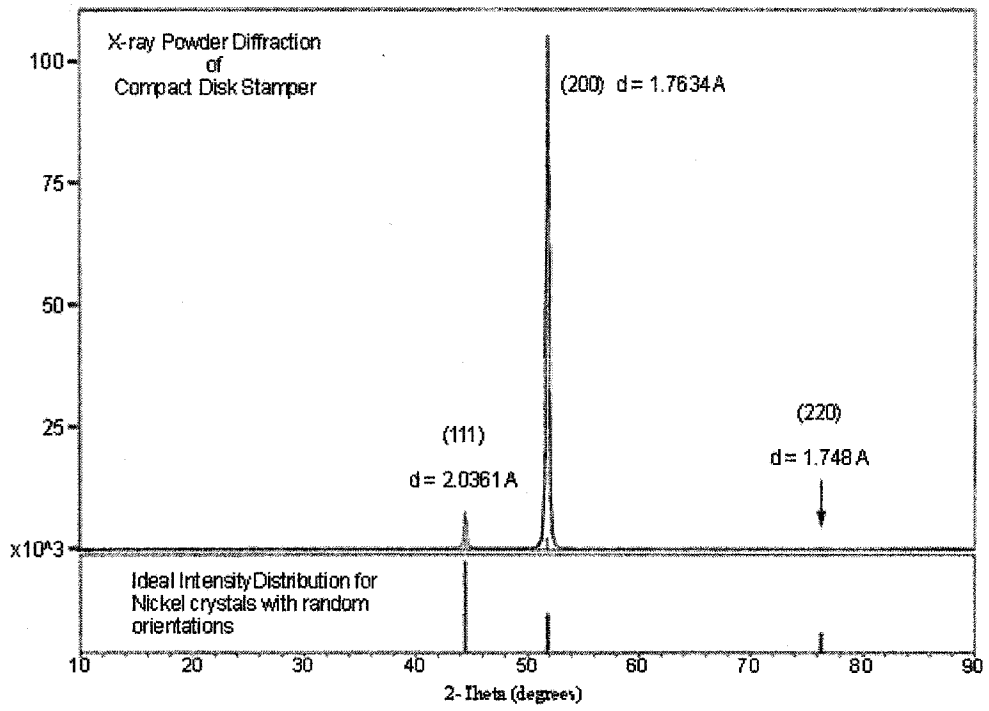


Figure L. X-ray diffraction pattern of CD stamper surface shows that a large number of nickel crystalline grains are preferentially oriented with their (100) crystalline axis perpendicular to the surface.

Discussion:

The data is recorded on the CD, after being pressed against a CD stamper, as steps arranged along a track spiraling out from the center of the disk. In the presence of a step, light reflected from its top will destructively interfere with light reflected from the area surrounding the step. Where a step is absent no such destructive interference occurs. Thus the intensity of the received light signal varies as the steps pass under the laser beam. The lengths of the steps and of the gaps between them transmit a code as a series of 1's and 0's. The steps on the recording track used to carry the music code are 0.5 μm wide. The length and spacing along the track of the steps is used to encode the signal, with a minimum step length of about 1μm. If a beam of light with a radius of 1 μm were centered on a long step, it would reflect about half of the incident light.

The 'pitch' of the track is only about 1.5 μm (as compared with the 100 μm for an LP record), which means that the CD can act as a reflection diffraction grating with a micrometer-sized grating constant. Application of some basic principles of physics will let us recognize that the CD can act like an optically periodic structure or grating. An experiment using a CD for white light diffraction is described by Cornwall [3].

The small size of the data is responsible for another identifying characteristic of the CD-ROM. The pits are close in size to the wavelengths of visible light. The interference of the light with the pits diffracts the light, creating the familiar "rainbow" pattern on the surface of the CD-ROM. The pits are approximately 1/4 the wavelength, or 0.5 μm high. The dimensions of the data pit give rise to the iridescence of a compact disk.

The physical dimensions of the data steps on the CD stamper is constrained by how light interacts within the material of the CD being fabricated. Unlike an LP record, the data track on a CD is 1.2 mm beneath the surface of the disk. The material of the disk, typically a polycarbonate plastic, has a refractive index of 1.55. Laser light with a wavelength of 780 nm in air changes to 503 nm in the plastic material of the CD [4]. The radius of the converging cone of light is 1.05 μm [4]. It is this dimension that dictates the minimum separation of the recorded tracks. Adjacent tracks set 1.6 μm apart puts one track beyond the reach of a beam scanning another neighboring track. Destructive interference occurs if the path difference between a ray reflected from a step and one reflected from the surrounding background surface is half a wavelength. Since the wavelength of the light within the CD is 503 nm, a path difference of about 250 nm is required. The half-wavelength path difference is achieved in the outward and return journey of the two rays by a step of height 125 nm.

Data CD-ROMs can have as many as 22,000 tracks and can store up to 650 megabytes of data or 75 minutes of audio information. An aluminum gallium arsenide diode laser giving light of wavelength 780 nm is commonly used. The recent development of a blue light laser has implications for the future design of compact and optical disk systems. A shorter wavelength that would be used to read the data from the disk would permit the use of narrower and more densely packed recorded tracks. This would result in larger data storage capacity or longer playing times allowable on future CDs.

Conclusion:

This experiment on the CD stamper demonstrates the necessity of investigating a material by multiple techniques so that one can get a comprehensive and self-consistent knowledge of its structure and composition at the macro-, micro- and the nano- scale. The choice of the familiar CD as an illustrative sample is powerful in delivering science and engineering education content to learners by connecting with their everyday experience. The ability to access sophisticated instrumentation remotely via the Internet facilitates the building of a "laboratory without walls" and brings a new meaning to hands-on experience.

References:

1. Gabor A. Samorjai, Introduction to surface chemistry and catalysis, John Wiley and Sons, Inc., New York, 1994. pp. 15-35

2. L.C.Feldman and J.W. Mayer, Fundamentals of Surface and Thin Film Analysis, North-Holland, New York (1986).

4. John A. Cope, "The Physics of the Compact Disc", Physics Education, 28, 15-21 (1993).

3. Malcolm G. Cornwall, "CD Means Colourful Diffraction", Physics Education 28, 12-14 (1993).

Comments:

A discovery-based lesson in determining the data capacity of a compact disk using images obtained from scanning probe microscopy images and other information can be found at:

http://invsee.eas.asu.edu/Modules/size&scale/unit7/unit7.htm#tea

Acknowledgement:

The authors would like to thank Timothy Karcher for performing the AES experiments, Barry Wilkens for performing the RBS/PIXE experiments and Dr. Thomas Groy for performing the x-ray diffraction experiments at ASU. We also thank the Goldwater Materials Science Laboratories and the Multi-user Scanning Probe Microscopy Facility within the Center for Solid State Science and the X-ray Facility within the Department of Chemistry and Biochemistry at Arizona State University for the use of its analytical instrumentation. This work was made possible through funding from the National Science Foundation NSF/REC-9632740

PROJECT 100: ACCELERATED COMMERCIALIZATION OF FRP COMPOSITE BRIDGE DECK PANELS

Mark Murton

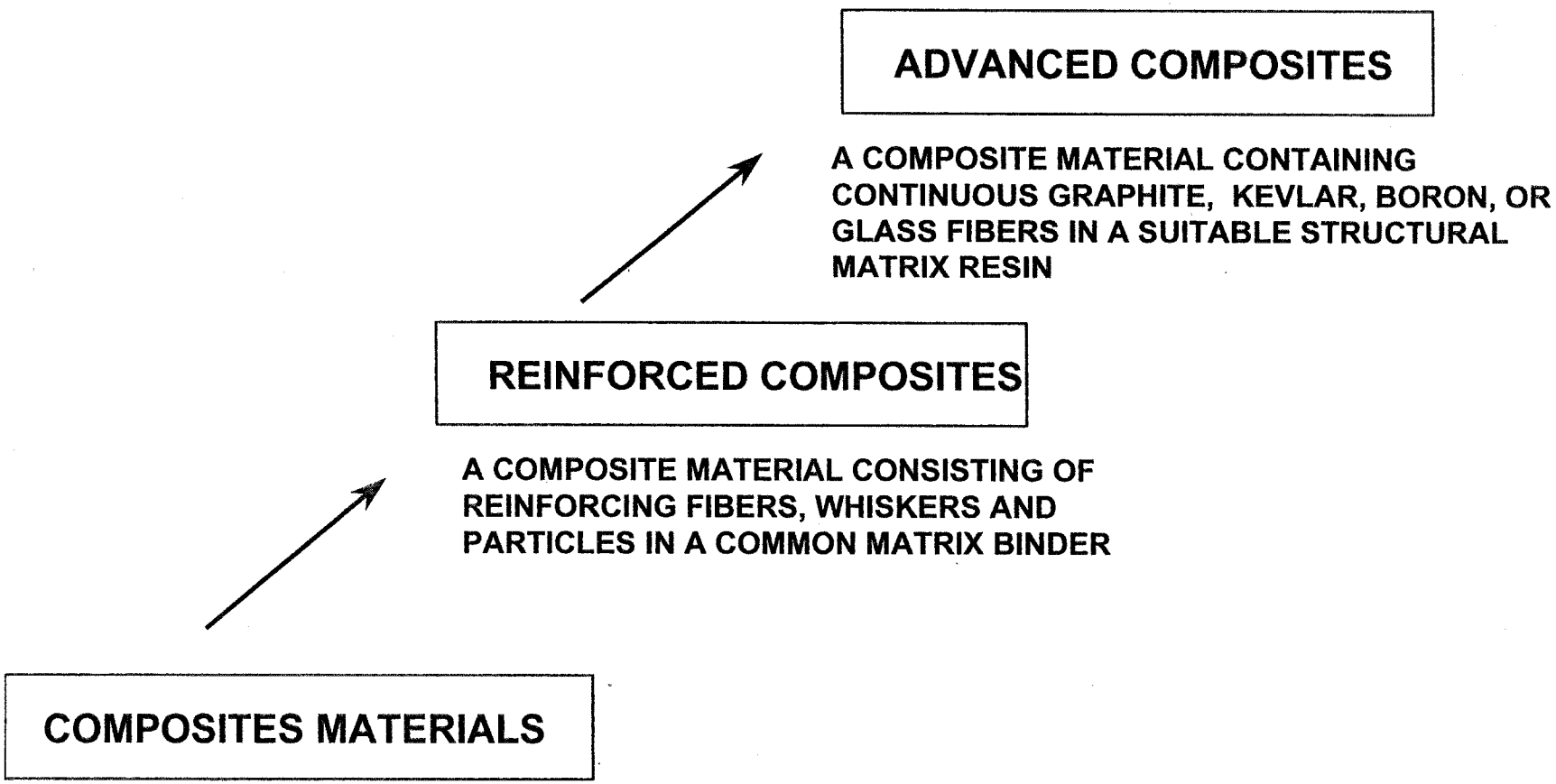
National Composite Center
2000 Composite Drive
Kettering, Ohio 45420

Telephone 937-297-9528
e-mail Mmurton@CompositeCenter.org

Mark Murton

PROJECT 100:
Accelerated Commercialization of FRP Composite Bridge Deck Panels

Composites 101...



Composites 101...

FIBERS

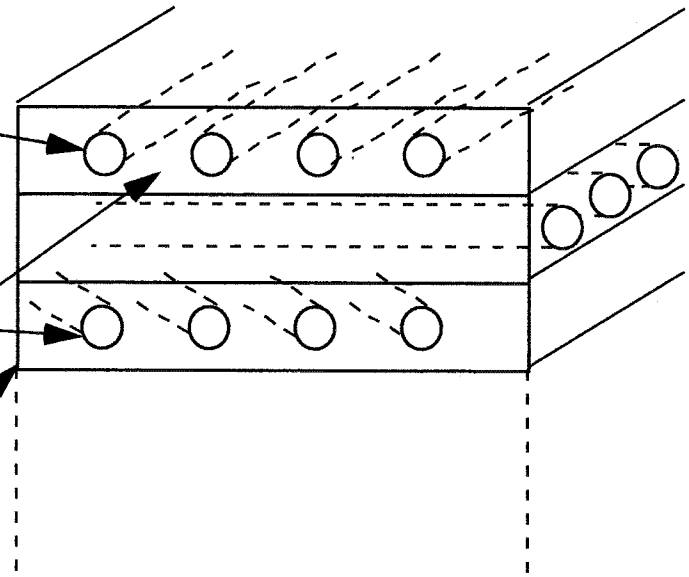
- HIGH STRENGTH
- HIGH MODULUS
- CONTINUOUS
- ALIGNED

INTERFACE

RESIN MATRIX/BINDER

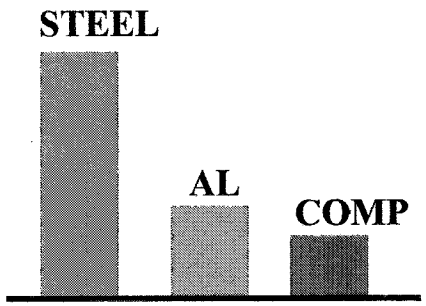
- LOW STRENGTH
- LOW MODULUS

PLY/LAMINA

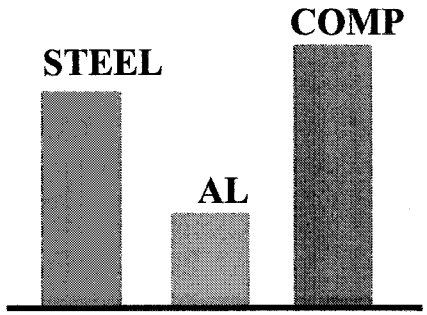


COMPOSITE LAMINATE

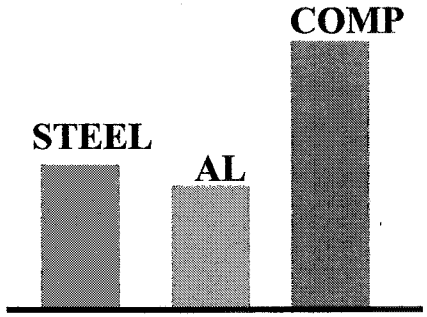
COMPOSITES vs METALS



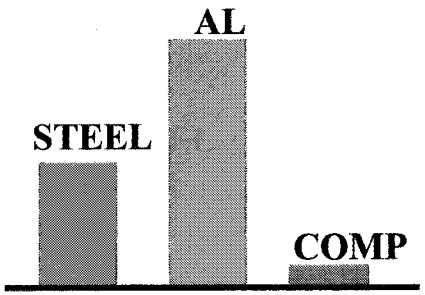
WEIGHT



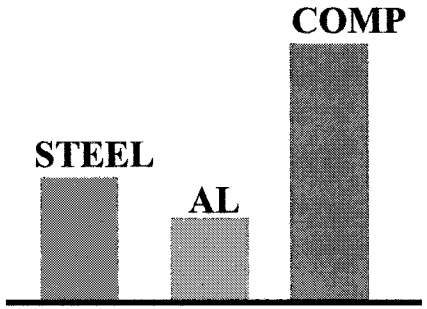
STIFFNESS



STRENGTH



THERMAL EXPANSION



FATIGUE RESISTANCE

PROJECT 100

- **Educational Challenges:**
  - **Polymer Composites: A Relatively New Class of Materials**
  - **"Body of Knowledge" Not Well Dispersed**
  - **Proprietary Methods and Materials**
  - **Non-Homogeneous, Non-Isotropic**
  - **Art *versus* Science**

WHAT IS PROJECT 100?

- **An Ohio Initiative to Design, Manufacture, and Install All-Composite Bridge Decks**
  - **In each of Ohio's 88 Counties**
  - **In each of ODOT's 12 Districts**
  - **100,000 square feet of deck in '00-'01**
  - **750,000 square feet total over 6 years**

PROJECT 100

- **Goal: Economic Development and Job Creation for Ohio**
  - **Build a New Industry in Ohio to Support An Expanding Market for FRP Composite Bridge Decks**

PROJECT 100

- **How Will The Economic Development Goal be Accomplished?**
  - **Significant Cost Reduction**
  - **Education and Outreach**
  - **"Leveraged Learning"**
    - **Across Projects**
    - **Across Programs**
  - **Market Development**

Why Bridge Decks?

- Infrastructure is Largest "Untapped" Market for Composites
- Technical Feasibility Established.. Poised to Move Into Rapid Commercialization Via Cost Reduction
- State Need + National Need = Large Market Potential

PROJECT 100

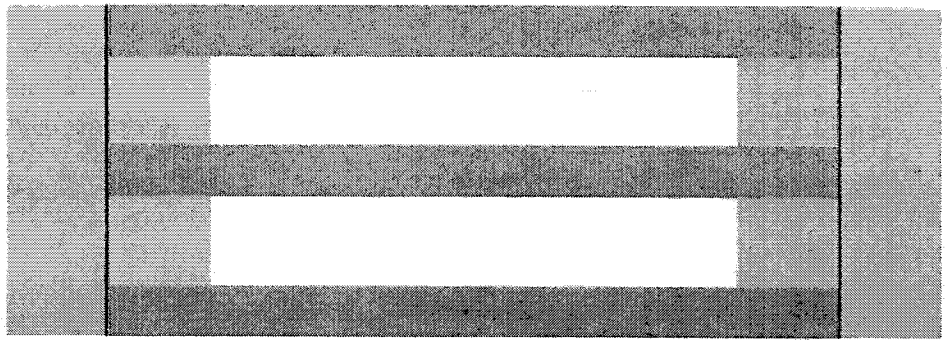
- **Aging Infrastructure Calls For Innovative Ideas**

  - Federal studies declare ~30% of US bridges structurally deficient or functionally obsolete
  - Bridges designed w/ life expectancy of 50 years
  - Majority of bridges approaching 50 year point
  - Designed 50 years ago for traffic volumes & truck loads of the 1950s and 1960s
  - Primary problem is corrosion of steel
    - -- high maintenance costs
    - -- loss of capacity
  - Result is many postings and closures

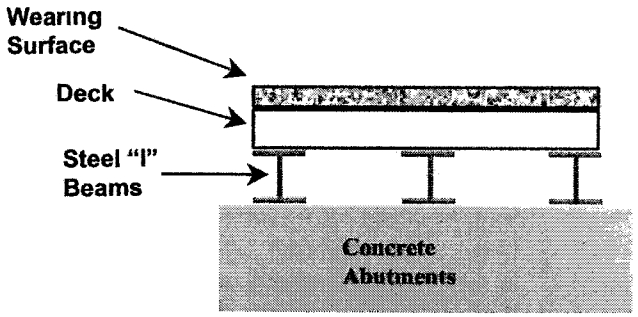
- **The Drive Is On Toward Long-Life, Low-Maintenance Alternatives to Traditional Construction Materials**

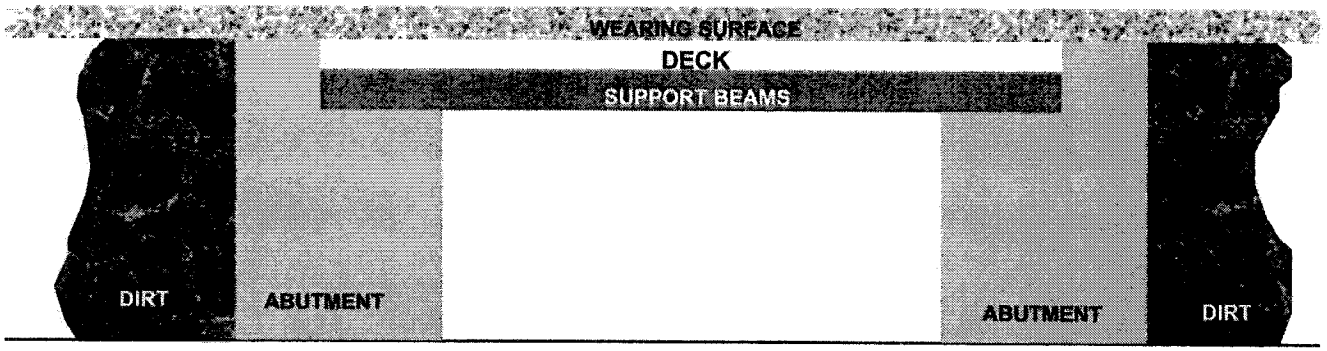
Bridge 101 ...

TOP VIEW



END VIEW





SIDE VIEW

STEEL "I" BEAMS

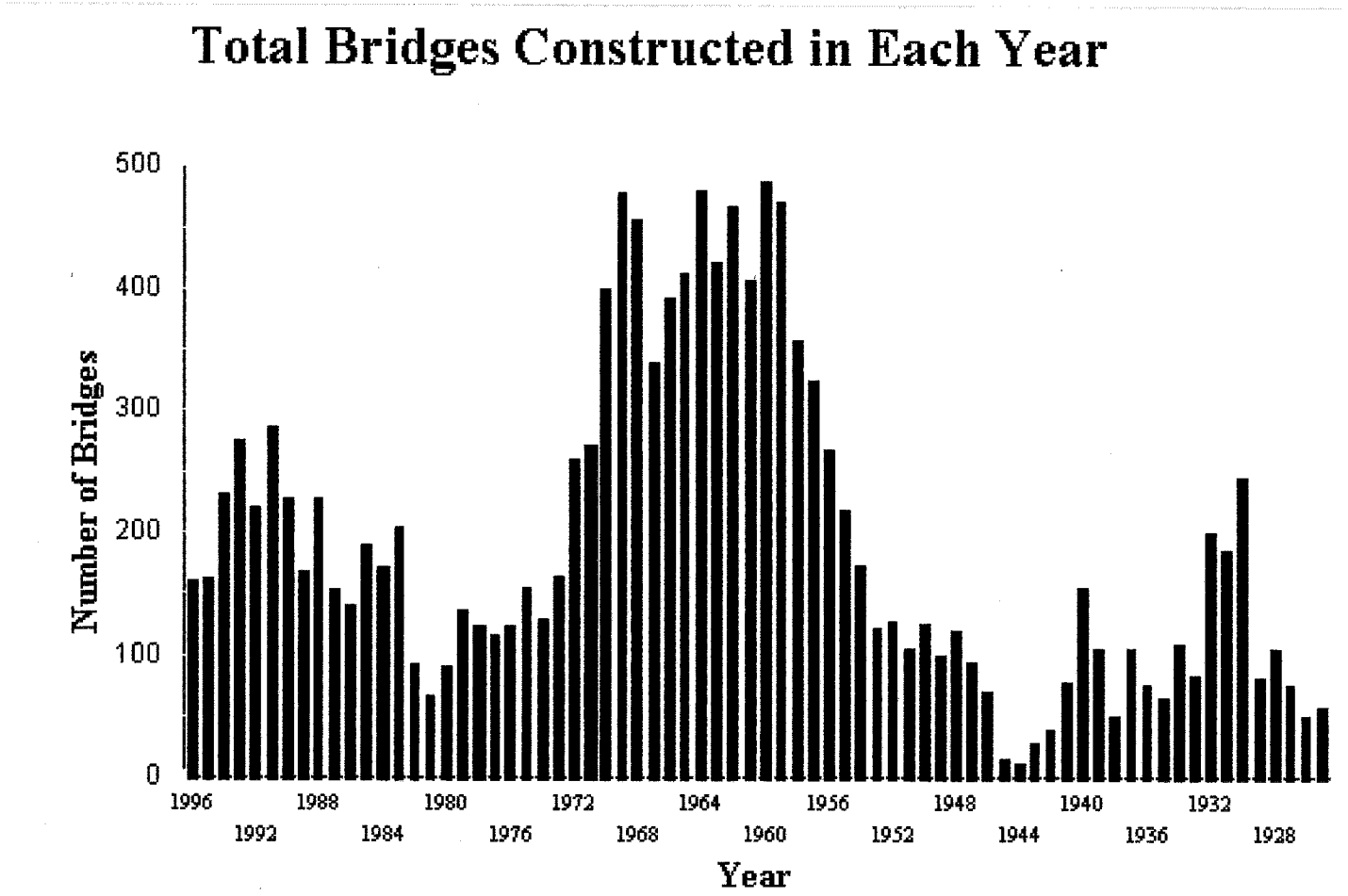
ABUTMENTS

DECK

- **Why Ohio?**
  - **Local Competitive Advantage: WPAFB, Universities, Industry**
  - **Ohio: 2nd Largest Bridge Inventory in Nation**
  - **Local Market. High Percentage of Ohio's Bridges in Need of Attention**
  - **Regional Market. Huge Potential Market Within 2-Day Delivery of Ohio (Rust Belt)**

Ohio Market Potential

- 42,890 bridges
- 125 million square feet of bridge deck
- 34 million square feet currently needs replacement;
  grow to 70 million sq ft over 20 years,
  100 million sq ft over 30 years
- Current costs are ~$30/sqft for installed deck;
  $1.0 billion current market;
  $2.1 billion over 20 years,
  $3.0 billion over 30 years


Total Bridges Constructed in Each Year
Number of Bridges
500
400
300
200
100
0
1996
1992
1988
1984
1980
1976
1972
1968
1964
1960
1956
1952
1948
1944
1940
1936
1932
1928
Year

Graph 2

PROJECT 100

National Market Potential:

- 600,000 bridges in National Bridge Inventory
- 3.2 billion square feet of bridge deck
- 1.0 billion square feet currently needs replacement; growing similar to Ohio over 20 years
- Current costs are ~$30/sqft for installed deck; $30 billion current market

PROJECT 100

- **How Does It Work?**
  - **State Subsidy Pays "Cost Difference" Between Conventional Materials and Composite Deck**
  - **NCC Works With Bridge Owners to Facilitate Design and Fabrication**
  - **Design is Collaborative Effort:**

    Owner + Consultant + Hardcore Composites + NCC
  - **NCC Manages the State Funding**

  - **OWNER AND INDUSTRY EDUCATION IS VITAL**

PROJECT 100

- **What is NCC's Role?**
  - **Manage State's Financial Investment**
  - **Facilitate Technology Transfer**
  - **Push Cost Reduction**
  - **Identify Project Sites**
  - **Get the Word Out**
  - **Collaborate With Other FRP Programs**
  - **Coordinate With ODOT and Other Agencies**

PROJECT 100

- **Approach: "Jump Start" a New Industry By:**
  - **Subsidizing Owners' Investment in Relatively Costly FRP Bridge Decks**
  - **Providing Sufficient Volume to a Single Supplier to Achieve Production Efficiencies**
  - **Pooling Process Development Funds From Various Sources to Further Drive Down Costs**
  - **Linking Volume Commitment To Supplier's Investment in Local Facilities**

- **SPECIFIC BENEFITS TO OWNERS:**
  - Reduced dead-load / Increased live-load capacity
  - Increased life expectancy
  - Reduced maintenance costs
  - Reduced roadway downtime
  - **NO ADDITIONAL COST FOR FRP COMPOSITE DECK**

PROJECT 100

- **To Achieve the Economic Growth Goals, We Must Offer a Product That Is:**
  - ✓ **Understood by Owners, Consulting Engineers, and Contractors**
  - ✓ **Available on a Competitive Basis**
  - ✓ **Supported by Commonly Recognized Design Methods**
  - ✓ **Produced to Recognized Standards**
  - ✓ **Easy to Inspect and Maintain**
  - ✓ **A Good Value**

PROJECT 100

- **Issues and Obstacles:**
  - **Cost**
  - **Liability**
  - **Lack of Standards**
  - **Lack of Awareness**
  - **Conservative Industry**

PROJECT 100

- **Applications**
  - **HS-25 Loads, L/800 Deflection, 8-foot Beam Spacing → 8-inch Deck Profile**
  - **Trusses, Steel Beams, Concrete Girders**
  - **Deck Replacement, Total Re-Build, New Construction**
  - **Simple Span, Multi-Span**
  - **Self-Supporting Decks**
  - **Low-Profile Decks for Lighter Loads or Narrower Beam Spacing**

PROJECT 100

- **"Bridge System" Considerations:**
  - **Deck-to-Beam Connections**
  - **Deck Panel Joints**
  - **Deck-to-Wear Surface Interface**
  - **Guardrail Attachments**
  - **Inspection and Maintenance**

PROJECT 100

- **Program and Industry Focus Areas:**
  - **Owner, Consultant, and Contractor Acceptance**
  - **Validation of Durability Claims**
  - **Education and Training**
  - **Cost Reduction**
  - **"Total Project Cost" and "Life Cycle Cost" Considerations**

PROJECT 100

- **Program and Industry Focus Areas:**
  - **Generic (non-Proprietary) Specification for Competitive Procurement**
  - **Consistency in Details**
  - **Qualified Designs, Processes, and Products**
  - **"Total System" Approach**
  - **Rational Design Methodology**

PROJECT 100

- **Fundamentally, Project 100 Is**
  - **A Focused Effort to Accelerate The Acceptance and Commercial Viability of a New Construction Material**
  - **A Learning Opportunity For Engineers, Contractors, Owners, And Suppliers**
  - **An Economic Development Initiative For The State of Ohio**
- **Project 100 Is Not**
  - **A Composites R&D Program**
  - **A Series of Demonstration Projects**

PROJECT 100

- compositecenter.org

- Mark Murton, VP Infrastructure Sector
  937-297-9528
  mmurton@compositecenter.org

BASIC CERAMICS: FIRING TEMPERATURE AND SIZE EFFECTS

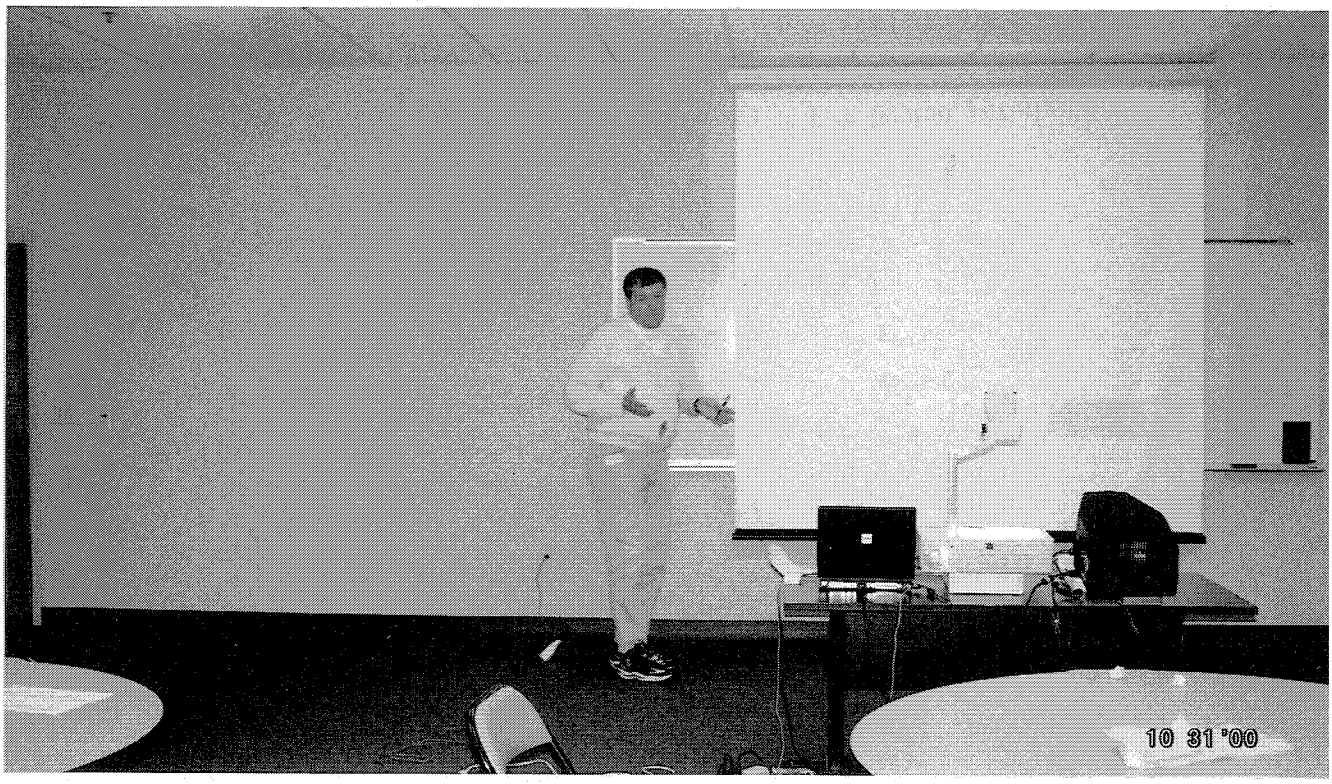
Kurt C. Schulz

University of the Pacific
Mechanical Engineering Department
3601 Pacific Avenue
Stockton, California 95211

Telephone: 209-946-3081
e-mail kschultz@uop.edu

Biography:

Dr. Kurt C. Schulz was recently promoted to associate rank and assigned the role of lower division director for the school of engineering at University of the Pacific where providing quality undergraduate education is the primary focus. He earned a Ph.D. in 1992 from Southern Methodist University where he specialized in the testing and analysis of advanced composite joints. Dr. Schulz was instrumental in the development of a new engineering school in Puerto Rico (Turabo University) and has taught at the University of Sierra Leone, Louisiana State University and Southern University. His current focus is on the development of international ties with the school of engineering at UOP including study abroad, work abroad and student exchange programs.



Basic Ceramics: Firing Temperature and Size Effects

Kurt C. Schulz
University of the Pacific
Mechanical Engineering Department
Stockton, California 95211
USA

Key Words: Ceramics, Modulus of Rupture, Flexural Strength, Flexural Modulus, t-Test, Hypothesis Testing

Prerequisite Knowledge: General knowledge of bonding, atomic structure and mechanical properties of ceramic materials. Basic understanding of ceramic fabrication (firing) and the effects of porosity and flaws on the strengths of ceramic materials. Although not mandatory, a basic background in statistical methods, specifically the t-test, hypothesis testing and level of significance, would be beneficial.

Objectives: There are two primary objectives: (1) to gain an understanding of the mechanical properties, and underlying atomic structures that cause the properties, of ceramic materials through application of Modulus of Rupture (MOR) tests, and (2) to gain an understanding of basic statistical methods through the application of the statistical t-test to hypothesize about the difference between population means.

Equipment and Materials:

1. Universal Testing Machine with Small Capacity Load Cell (100 to 500 lb Max)
2. 3-Point Bend Test Fixture (1.5" Span Length)
3. Rescor Cer-Cast 750 Advanced Ceramic (SiO_2) Castable Mix (Base/Activator)
4. Premade Rectangular Ceramic Block Test Specimens
   - One 2" X 1.5" X 0.125" Specimen Cured at 225°F
   - One 2" X 1.5" X 0.125" Specimen Cured at 1750°F
   - One 2" X 0.5" X 0.125" Specimen Cured at 225°F
   - One 2" X 0.5" X 0.125" Specimen Cured at 1750°F
5. PC with Data Acquisition Capability
6. Measurement Instruments: Calipers and/or Micrometers

Introduction:

In ductile materials, the stress-strain behavior is generally found by applying the standard tensile test. The stress-strain curve typically goes through a maximum that is where the tensile strength is located (see Figure 1). Failure occurs at a lower stress after necking has reduced the

cross sectional area supporting the load On the other hand the stress strain behavior of brittle ceramics is not typically ascertained using a tensile test There are many reasons as to why the tensile test is not generally used with ceramics

1 it is difficult to prepare and test specimens having the required geometry
2 it is difficult to grip brittle materials without fracturing them
3 surface flaws often cause premature failures and
4 ceramics fail after only about 0 1% strain thus specimens must be perfectly aligned in order to avoid the presence of bending stresses

Due to these constraints a more suitable transverse bending test is generally used when testing ceramics

In the bend test (or flexure test see Figure 2) a bar specimen having either a circular or rectangular cross section is bent until fracture using a three or four point loading technique At the point of loading the top surface of the specimen is placed in a state of compression and the bottom surface is in tension Stress is computed from the specimen thickness the bending moment and the moment of inertia of the cross section The maximum tensile stress exists at the bottom surface of the center of the specimen, directly below the point of load application Since the tensile strengths of ceramics are about one tenth of their compressive strengths and fracture occurs on the tensile specimen face the bend test is a valid substitute for the tensile test

For a 3 point bend test of a rectangular bar the stress at fracture using the bend test is known as the Flexural Strength or Modulus of Rupture and is given by

$$\sigma_{fs} = \frac{3FL}{2wh^2}$$

where σ_{fs} = flexural strength F = fracture load L = length between outer supports (span length) w = specimen width, and h = specimen height (see Figure 2)

The results of the bend test are similar to stress strain curves however the stress is plotted versus deflection rather than versus strain

The modulus of elasticity in bending the flexural modulus is determined from the linear portion of the stress deflection curve and is given by

$$E_{fs} = \frac{L^3(F_1 - F_2)}{4wh^3(\delta_1 - \delta_2)}$$

where E_{fs} = flexural modulus F_{max} = maximum applied force δ = beam deflection at F_{max} $F_1 = 2/3\ F_{max}$ with δ_1 @ $2/3\ F_{max}$ and $F_2 = 1/3\ F_{max}$ with δ_2 @ $1/3\ F_{max}$

Because cracks and flaws tend to remain closed in compression brittle materials are generally designed such that only compressive stresses act on the part

There is often considerable variation and scatter in flexural strength for many specimens of a specific brittle ceramic material. This phenomenon may be explained by the dependence of flexural strength on the probability of the existence of a flaw that is capable of initiating a crack. This probability varies from specimen to specimen of the same material and depends on fabrication technique and any subsequent treatment. Specimen size also influences flexural strength; the larger the specimen, the greater the probability of critical flaw existence, and the lower the flexural strength. The t-Test is a statistical method that is applied to determine whether or not significant mean differences exist between two sets of repeated measures data. The method will be applied to determine whether or not a specimen size effect is evident in the Modulus of Rupture tests being conducted in this experiment.

A small sample-size test (less than 30 measurements) of the significance of the difference between two population means may be based on the t statistic. The t-test is generally applied when at least one of the sample sizes, n_1 or n_2, is less than 30. If the samples (tests) are random and independent and derive from approximately Normal distributions with similar standard deviations, then the t statistic can be applied to determine if the sample means are different:

$$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where $\bar{x}_1$ = sample mean form the first data set, $\bar{x}_2$ = sample mean form the second data set, n_1 = number of data points in the first data set, n_2 = number of data points in the second data set, s_1 = sample standard deviation of the first data set, and s_2 = sample standard deviation of the second data set.

Recall that Sample Standard Deviation is given by

$$s = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n - 1}}$$

The decision as to whether or not one mean is greater than another is based on the t-sampling distribution with $n_1 + n_2 - 2$ degrees of freedom. Applying the one-sided alternative, that $\bar{x}_1$ is Not Greater Than $\bar{x}_2$, the level of significance, α, is identified by t_α as indicated in Figure 3.

The following procedure can be utilized in the application of the t-test:

1. State the Null Hypothesis as H_O: $\bar{x}_1$ Not Greater Than $\bar{x}_2$
2. State the Alternative Hypothesis as H_A: $\bar{x}_1$ Greater Than $\bar{x}_2$
3. Select a Level of Significance (α): 0.05 is generally used.
4. Criterion: Using the t-table (see Table 1), determine the critical value of t_α for $n_1 + n_2 - 2$ Degrees of Freedom.
5. Calculate t based on the two data sets.
6. Decision: Reject the Null Hypothesis if $|t| > t_\alpha$; Do Not Reject the Null Hypothesis if $|t| < t_\alpha$.

Example: Two sets of tensile strength test data were collected as indicated below. It is thought that Zinc Coated parts are stronger than Tin Coated parts. Use the 0.05 Level of Significance to determine whether the Mean Strength of the Zinc Coated parts can be considered to be Greater Than the Mean Strength of the Tin Coated parts.

Tin Coated Parts – Tensile Stength (MPa): 55, 56, 49, 61, 58

Zinc Coated Parts – Tensile Strength (MPa): 62, 63, 53, 59, 60

Answer: $t = 5.404$, $t_\alpha = 1.860 \rightarrow$ Reject H_O ($\bar{x}_1$ Not Greater Than $\bar{x}_2$) $\rightarrow$ Accept H_A ($\bar{x}_1$ Greater Than $\bar{x}_2$)

Procedure:

Modulus of Rupture (MOR) tests will be conducted in this experiment. The MOR tests will involve three-point bending of specimens through application of a compressive load at the specimen center.

1. Measure and record the Span Length, L, for the base of the fixture (all of the specimens are nominally 2.0 inches long, but L is based on the Span Length). Record the Span Length below.

   Span Length = _____

2. Prior to each test, measure and record the specimen's center Width and Thickness and record the values in the data sheet provided (next page).

3. Each group will be testing 4 specimens as indicated in the table below (one replication per cell for each group).

4. Conduct 4 MOR tests collecting the Load versus Deflection (Stroke) data for each specimen through brittle fracture.

5. Apply the t-Test to the combined Flexural Strength results of all of the current semester lab groups to investigate whether or not there's a Curing Temperature Effect at a 0.05 Level of Significance:

   a.) For the w = 0.50 inch Specimens.

   b.) For the w = 1.50 inch Specimens.

Nominal Specimen Width (Inches)	Firing Temperature (°F)	
	225	1750
0.50	1	1
1.50	1	1

MODULUS OF RUPTURE DATA SHEET

Test #	Thick-ness (in)	Width (in)	Firing Temp. (°F)	F_{MAX} (lb)	δ_{MAX} (in)	F_1 (lb)	δ_1 (in)	F_2 (lb)	δ_2 (in)	Flexural Strength (psi)	Flexural Modulus (psi)

6. Apply the t-Test to the combined Flexural Strength results of all groups, investigate whether or not there's a Size Effect at a 0.05 Level of Significance:
   a.) For the Specimens Cured at 225°F.
   b.) For the Specimens Cured at 1750°F.
7. Show sample t-Test calculations and present your findings.
8. Write a brief Safety Analysis below that explains the potential hazards of the experiment. (For each potential hazard, identify the potential hazard, briefly explain the potential hazard, and then describe the steps that were, or should be, taken to protect against the potential hazard)
9. Explain what the data means and discuss your results with respect to theoretical expectations.
10. Discuss any experimental errors that may have occurred in this experiment.
11. Make conclusions based on experimental evidence. Present your conclusions in the form of a concise summary of your findings that you would hand to your boss; support the statements with experimental evidence and comparisons with applicable theory.

Note: Lab Reports MUST be in accordance with the Course guidelines - See Course Website!

Comments:

As presented here, the experiment is a one-session study in which the data collected by all students enrolled in the lab course for a given semester are compiled and analyzed by the students. The specimens are fabricated by the instructor (a technician could be used if available) prior to the lab. A cutout rubber sheet and flat acrylic sheet comprise the mold that is used with a Cer-Cast castable mix to form the ceramic samples (see Figure 4 - contact author for details). This format is excellent for an introductory materials science course with a one-credit laboratory. In a more advanced and/or longer formatted course, the fabrication and curing of the samples could be assigned to the students.

The firing effect has always been found to be statistically significant for both the smaller and larger sample sizes. The size effect is also generally found to be statistically significant, but for data sets with large standard deviations the strength difference can be overshadowed by data scatter. It appears that experimental diligence is required; large data shifts are sometimes observed between the data sets collected by different groups on nearly identical samples (repeated measures).

Unless a statistics course is a prerequisite for the course in which this lab is conducted, the instructor should spend some time explaining the statistical methods being applied here. At UOP most students appear to be unfamiliar with the t-test, hypothesis testing, levels of significance, etc. prior to enrolling in the lab course; it's important that the students not only make the proper inferences, but they should also be capable of explaining what the results signify.

It should also be noted that the expressions for flexural strength and flexural modulus are based on fundamental mechanics of materials concepts; students with a basic mechanics of materials background should be able to derive these expressions.

References:

1. D.R. Askeland, The Science and Engineering of Materials, PWS Publishing Company, Boston (1994).
2. L. Ott, An Introduction to Statistical Methods and Data Analysis, PWS-Kent Publishing Company, Boston (1988).

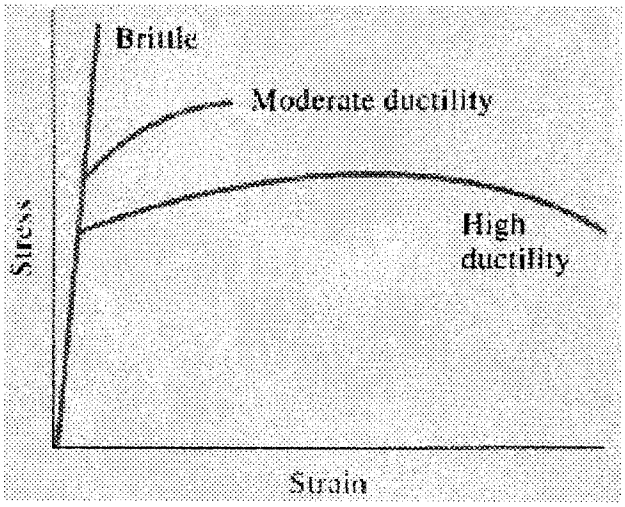


Figure 1 - The stress-strain behavior of brittle materials compared with that of more ductile materials. [Askeland, 1994]

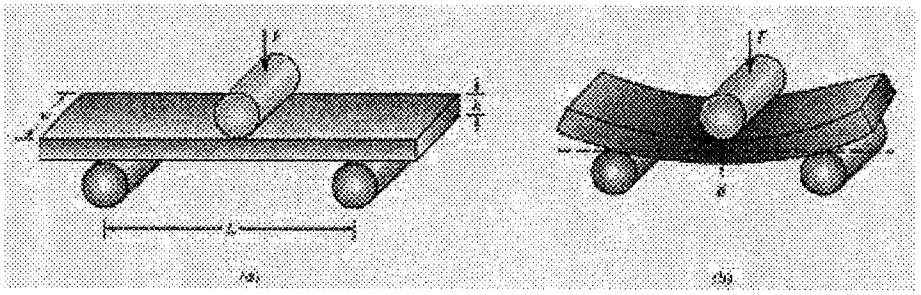


Figure 2 - (a) The bend test often used for measuring the strength of brittle materials, and (b) the deflection obtained by bending. [Askeland, 1994]

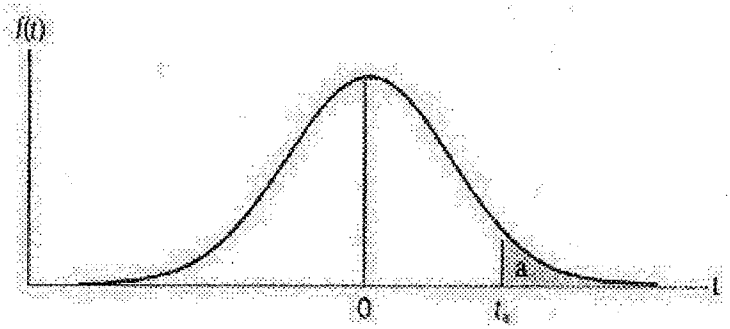
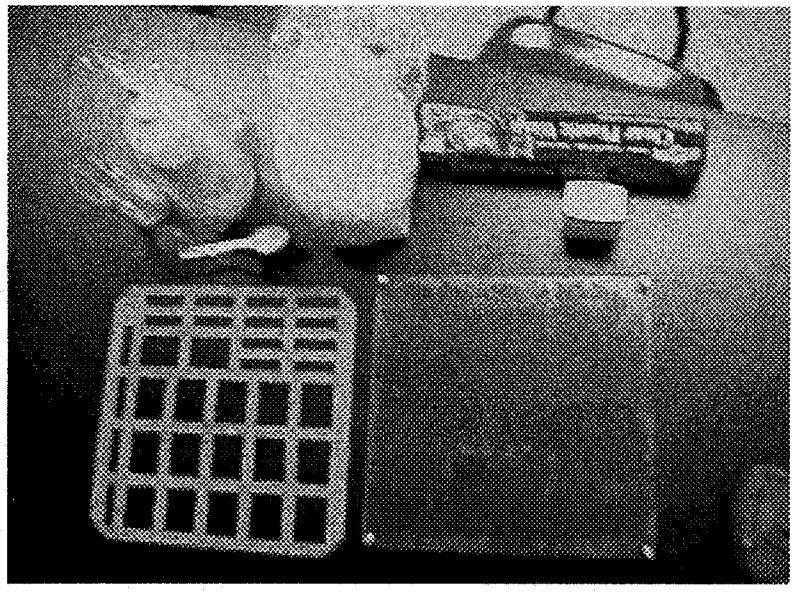
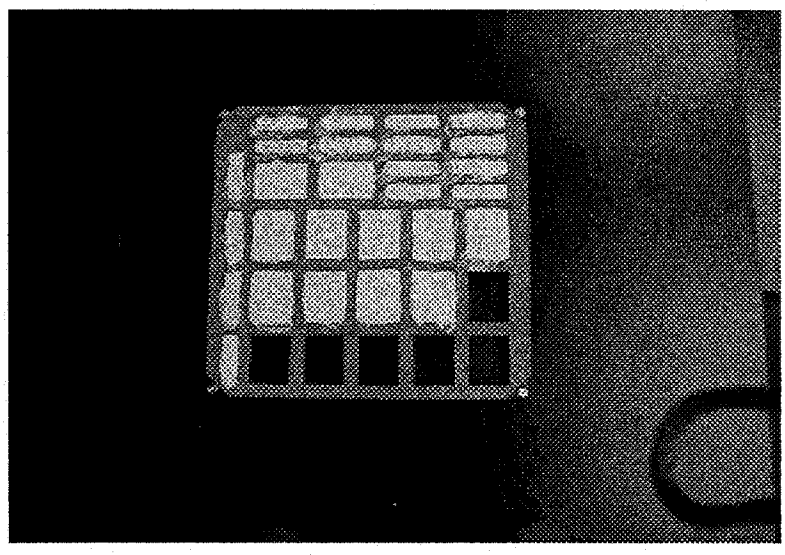


Figure 3 - Graphical Depiction of the t-Distribution. [Ott, 1988]



(a)



(b)

Figure 4 - (a) Photograph of the ceramic specimen fabrication materials and supplies, and (b) Photograph of poured specimens in mold.

Table 1 - Percentage Points of the t-Distribution. [Ott, 1988]

Percentage Points of the t Distribution

df	$\alpha = .1$	$\alpha = .05$	$\alpha = .025$	$\alpha = .01$	$\alpha = .005$	$\alpha = .001$
1	3.078	6.314	12.706	31.821	63.657	318.309
2	1.886	2.920	4.303	6.965	9.925	22.327
3	1.638	2.353	3.182	4.541	5.841	10.215
4	1.533	2.132	2.776	3.747	4.604	7.173
5	1.476	2.015	2.571	3.365	4.032	5.893
6	1.440	1.943	2.447	3.143	3.707	5.208
7	1.415	1.895	2.365	2.998	3.499	4.785
8	1.397	1.860	2.306	2.896	3.355	4.501
9	1.383	1.833	2.262	2.821	3.250	4.297
10	1.372	1.812	2.228	2.764	3.169	4.144
11	1.363	1.796	2.201	2.718	3.106	4.025
12	1.356	1.782	2.179	2.681	3.055	3.930
13	1.350	1.771	2.160	2.650	3.012	3.852
14	1.345	1.761	2.145	2.624	2.977	3.787
15	1.341	1.753	2.131	2.602	2.947	3.733
16	1.337	1.746	2.120	2.583	2.921	3.686
17	1.333	1.740	2.110	2.567	2.898	3.646
18	1.330	1.734	2.101	2.552	2.878	3.610
19	1.328	1.729	2.093	2.539	2.861	3.579
20	1.325	1.725	2.086	2.528	2.845	3.552
21	1.323	1.721	2.080	2.518	2.831	3.527
22	1.321	1.717	2.074	2.508	2.819	3.505
23	1.319	1.714	2.069	2.500	2.807	3.485
24	1.318	1.711	2.064	2.492	2.797	3.467
25	1.316	1.708	2.060	2.485	2.787	3.450
26	1.315	1.706	2.056	2.479	2.779	3.435
27	1.314	1.703	2.052	2.473	2.771	3.421
28	1.313	1.701	2.048	2.467	2.763	3.408
29	1.311	1.699	2.045	2.462	2.756	3.396
30	1.310	1.697	2.042	2.457	2.750	3.385
40	1.303	1.684	2.021	2.423	2.704	3.307
60	1.296	1.671	2.000	2.390	2.660	3.232
120	1.289	1.658	1.980	2.358	2.617	3.160
240	1.285	1.651	1.970	2.342	2.596	3.125
inf.	1.282	1.645	1.960	2.326	2.576	3.090

Source: Computed by P. J. Hildebrand.

USING HISTORICAL EXAMPLES TO ENHANCE TEACHING OF "MODERN" ENGINEERING AND SCIENTIFIC SUBJECTS

Daniel Eylon

Professor and Director
Graduate Materials Engineering
University of Dayton
300 College Park
Dayton, Ohio 45469-0240

Telephone: 937-229-2551
e-mail Daniel.Eylon@notes.udayton.edu

Daniel Eylon

USING HISTORICAL EXAMPLES TO ENHANCE TEACHING OF "MODERN" ENGINEERING AND SCIENTIFIC SUBJECTS

Presented at the:

National Educators' workshop
NEW: Update 2000

October 29 - November 1, 2000

At the:

National Composite Center
Kettering, Ohio

By:

Daniel Eylon
Graduate Materials engineering
University of Dayton

THE CHALLENGE OF TEACHING MATERIALS ENGINEERING

- **Materials Engineering** (and possibly other similar areas of engineering), **has been always perceived by students as an interdisciplinary area, which combines fragmented, sometimes disjointed, teachings from other disciplines**

- **The greatest challenge is teaching metals, ceramics, polymers, composites and nano-phase materials as a one coherent, connected and interrelated topical subject**

- **Although material categories may follow different physical principles, the logic behind their evolution and implementation, is almost always the same: the perpetual pursuit of better, yet more affordable, materials**

- **During my years of teaching, I have noticed that students are very receptive to learning about the history and evolution of different material categories. They enjoy learning about the driving forces behind the search of new materials and processes, about the early mistakes, misconceptions, and about technology "dead-ends"**

- **Meeting students many years after graduation, I have learnt that often, they remember those historical anecdotal facts better than the main body of the teaching**

- **As a result, I have incorporated in recent years more historical perspective into the teaching of my materials classes**

THE BENEFITS OF "TIMELINE - TEACHING"

- **The evolution of rather modern materials, such as steels** (the industrial revolution), **or nickel-base super alloys** (WWII), **present a very systematic, logical and often similar progress. By making an effort to present these to the students, it is possible to reap the following benefits:**
  - **Show similarity between the different alloy or material systems**
  - **Make it possible for the students to comprehend the origins of the ideas and the driving forces behind the technical and economical developments**
  - **Demonstrate to the students that the diverse world of engineering materials is, after all, not so fragmented and disjointed**
  - **Allow students to make their own "connections" in future learning**
  - **Make it easy to understand and remember the existence of the different alloy groups and categories, simply by remembering their time-line evolution**
  - **Increase the "long-term" memory of the topic area**
  - **Prevent the students from falling asleep during late evening classes**
- **The evolution of the following materials make good historical cases:**
  - **Steels [**wrought iron (1000BC to 19C); low-carbon steels (19C); tool steels (20C)**]**
  - **Aluminum [**C.M. Hall, (1890); Alcoa (1900); Wright Flyer (1903); Duralumin (1906)**]**
  - **Nickel-base alloys [**Creep resistance through Ni, Cr (1945) and γ' precipitates (1960)**]**
  - **Structural ceramics**
  - **Organic composites**

THE BENEFITS OF "HISTORICAL - TEACHING"

- In addition to "latter-day" historical facts, there is a great educational value in teaching the early history of material or technology developments

- The introduction of the Stone-age, Copper-age, Bronze-age and Iron-age, from 5000BC to 1000BC, both in the Middle-East and China, present cases for material development that were just as revolutionary and far reaching as the introduction of aerospace alloys or microprocessor materials of our age

- The early technology breakthroughs revolutionized food production, clothing and shelter making, and therefore expand the human population from the warm and fertile Africa into the more hostile ice-age Asia and Europe

- The study of "cutting-edge" technologies, such as sword making, teaches the students that "modern concepts", such as MMC, graded materials, composite structures and directional processing, existed as early as 1000BC

- Historical reviews demonstrate that earlier technologists were innovative, original and imaginative as today's scientists. Very few know that the investment casting technique, used to produce single crystal nickel-base alloy jet engine blades, was developed in Egypt as early as 3100BC, or that the use of ceramics in compression loading started in the Roman arch and climaxed in the Gothic cathedrals

- Such facts will increase the appreciation for earlier generations and enhance the interest in Materials Engineering or any engineering area with a historical past

WHAT DOES IT TAKE TO TEACH "HISTORY - ASSISTED" ENGINEERING

- First of all and above all the love for this subject and the love for this approach
- Collect data and information from diverse "non-textbook" sources
- Read books and articles on the history of science. Many professional journals, such as the JOM, started in recent years to include historical technology articles
- Encourage teachers and students to visit technology oriented museums
- Travel extensively to countries with rich technological history such as the Middle-East, Italy, England, Germany, France, China and Japan
- Watch technology oriented TV series such as Nova, Connections etc.
- Encourage students to share in class their knowledge and experience
- Develop your own material, based on your personal interests. It will always come across more lively and more genuine

ANTI-STOKES TRANSITIONS IN POLYFLUORENE

Bruno Ullrich

Assistant Professor
Department of Physics & Astronomy
Center for Materials Science
Bowling Green State University
Bowling Green, Ohio 43403-0224

Telephone: 419-372-7245
e-mail bruno@newton.bgsu.edu

Biography:

Bruno Ullrich was born in Vienna, Austria, in 1961. He received the Ph.D. degree in Physics in 1988 from The University of Vienna. He held post-doc and lecturer positions at The University of Strasbourg (France) and The Technical University of Graz (Austria), from 1989-1991 and from 1991-1993, respectively. He was employed as Industrial Technology Researcher at The University of Tokyo from 1993-1998, working on nonlinear optics and laser ablation of II-VI compound semiconductors. From 1998-2000, he studied at the Institute of Physical and Chemical Research (RIKEN) in Sendai (Japan) optically pumped semiconductor lasers. In March, 2000, he joined the Department of Physics and Astronomy at The Bowling Green State University in Ohio. His current research interests include ultra-fast spectroscopy and nonlinear optics on inorganic and organic semiconductors and laser ablation of thin semiconducting films.

Anti Stokes Transitions in Polyfluorene

Bruno Ullrich
Assistant Professor
Department of Physics & Astronomy, Center for Materials Science, Bowling Green State University, Bowling Green, Ohio 43403 0224

Key Words:
Ultrafast pulsed laser spectroscopy organic semiconductors, highly excited semiconductors Anti Stokes transitions two photon absorption up conversion blue light emission

Prerequisite Knowledge:
Operation of pulsed laser systems semiconductor physics optics nonlinear optics

Objective:
Up conversion To generate blue light emission at 400 nm out of an organic semiconductoı (polyfluorene) by the use of laser excitation at 800 nm

Equipment:
Fs laser system lenses optical filters neutral density filters fibers computer controlled spectrometer

Independent Variables:
Energy gap of polyfluorene (400 nm i e 3 1 eV at 300 K) ambient temperature (300 K)

Dependent Variables:
Concentration of the excited photocarriers

Machine Parameters to be held constant:
Output wavelength of the laser (804 nm) pulse width (200 fs) repetition rate (249 kHz) of the pulses

Introduction:
The Anti Stokes process (also called two photon process or up conversion) underlies the transition via a virtual state within the gap of a semiconducting material I e two phase coherent photons cooperate in exciting an electron to twice the energy of a single photon Hence the sample absorbs light to which it should be transparent As a consequence electron hole pair generation takes place This pair generation can be detected as photoluminescence emitting photons of greater energy than that of the exciting photons In the current experiment polyfluorene is excited at 804 nm resulting in a blue light emission close to 400 nm Due to reasons of probability, the intensity of the emitted blue light depends upon the square of the incident intensity This square dependence is checked by changing the laser intensity by neutral density filters

Procedure:
1 The experiment is started with the maximum of the available laser intensity ($\approx 10^9$ Wcm^{-2}) by recording the emission at 400 nm
2 Afterwards a neutral density filter, which transmits about 63% of the incoming laser light is put in the beam and the spectrum is recorded
3 The procedure is repeated by adding neutral density filters till the impinging laser intensity is reduced by about two orders of magnitude

The experiments are carried out in co operation with Raoul Schroeder Bowling Green State University Department of Physics and Astronomy, Bowling Green OH and Virginia Tech, Department of Physics Blacksburg, VA Willi Graupner Virginia Tech, Department of Physics Blacksburg VA, Ullrich Scherf Max Planck Institut fuer Polymerforschung, Mainz Germany

A REVOLUTION IN MANUFACTURING COMPOSITES: CURING WITH ELECTRON BEAMS

Don Klosterman

Laboratory for Research on Electron Beam Curing of Composites
University of Dayton
300 College Park
Dayton, Ohio 45469-0131

Telephone: 937-229-2517
e-mail Don.Klosterman@notes.udayton.edu

Don Klosterman

A Revolution in Manufacturing Composites: Curing With Electron Beams

UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE

Don Klosterman, Ph.D.

Coordinator and Radiation Safety Officer

Laboratory for Research on Electron Beam Curing of Composites

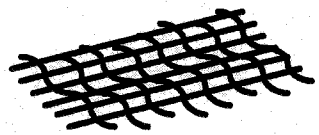
UNIVERSITY of DAYTON

300 College Park, Dayton, OH 45469-0131
937-229-2517 (phone) 937-229-2503 (fax)

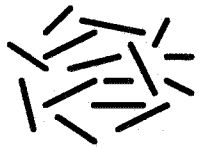
www.udri.udayton.edu/ebeam

Composite Manufacturing

Continuous (unidirectional)



Fabric: woven, braided, stitched



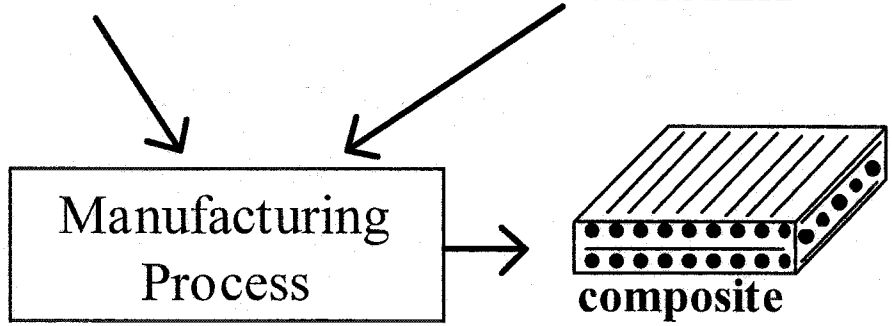
Chopped / Short fiber

Polymer
- **thermoset**
- **thermoplastic**

Metal

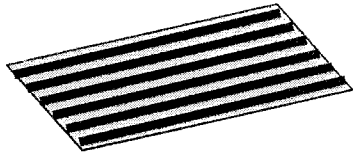
Ceramic

FIBER **MATRIX**

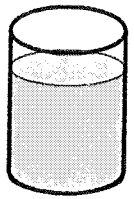


Polymer Matrix Composites
Typical Manufacturing Process Step 1

carbon fibers



"Prepreg"
(pre-impregnated fiber preform)



Liquid
thermoset resin
(e g epoxy)

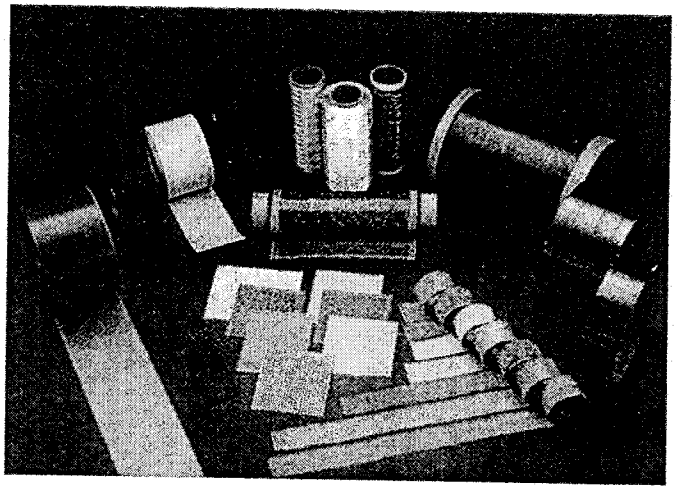
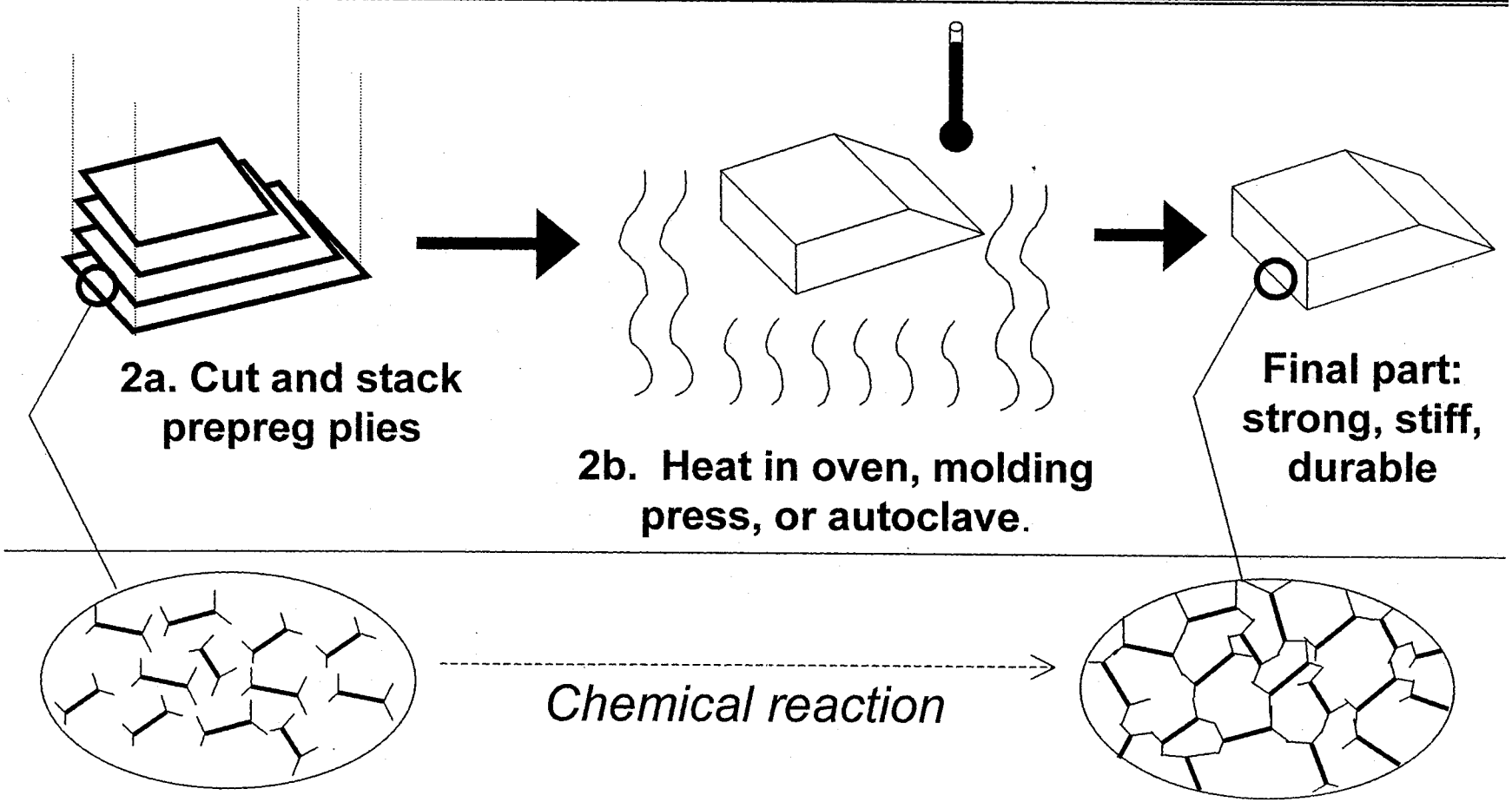


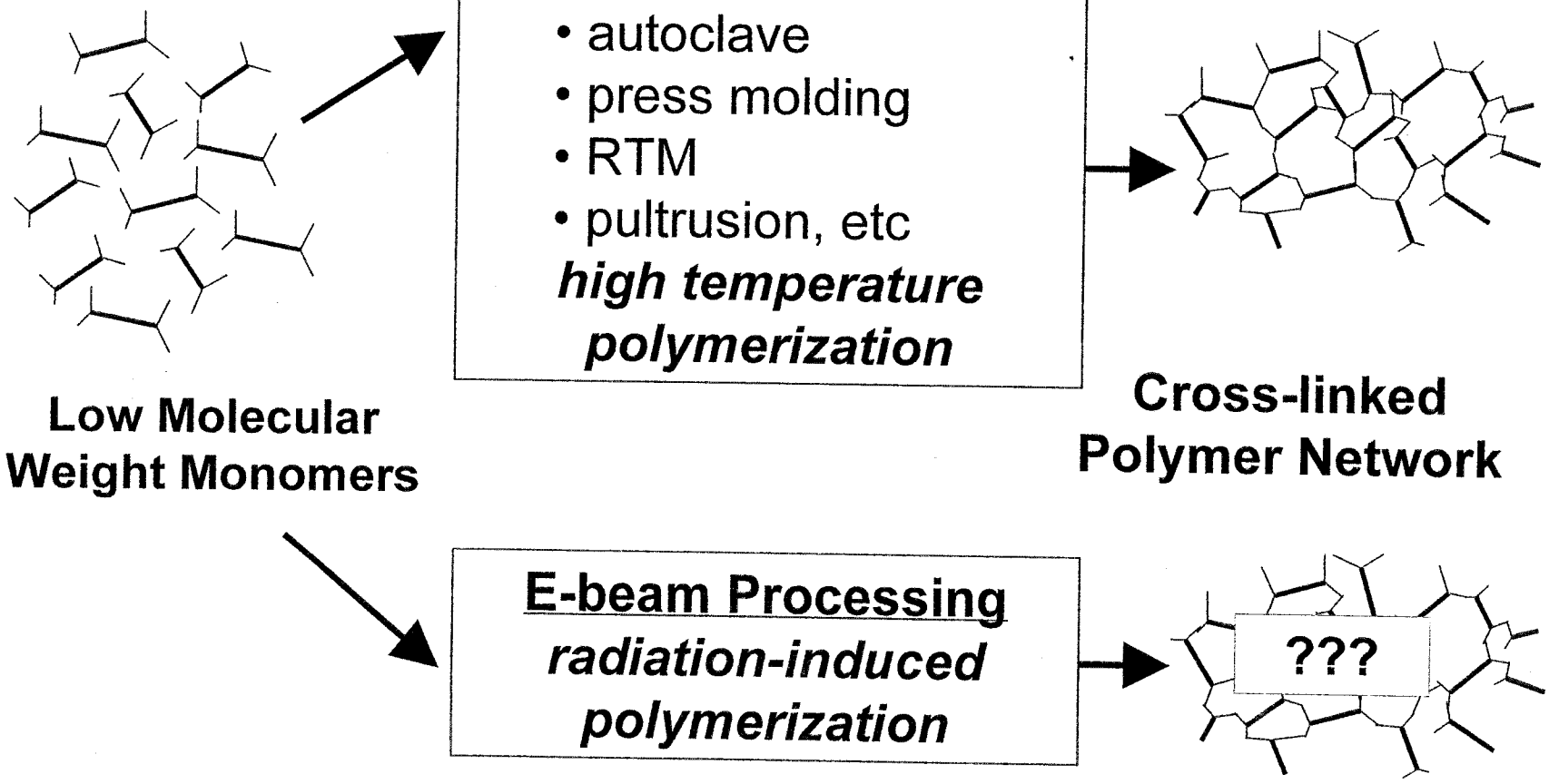
Photo courtesy Cytec Fiberite, *High Performance Composites*, May/June 2000, p. 32.

Polymer Matrix Composites

Typical Manufacturing Process : Step 2

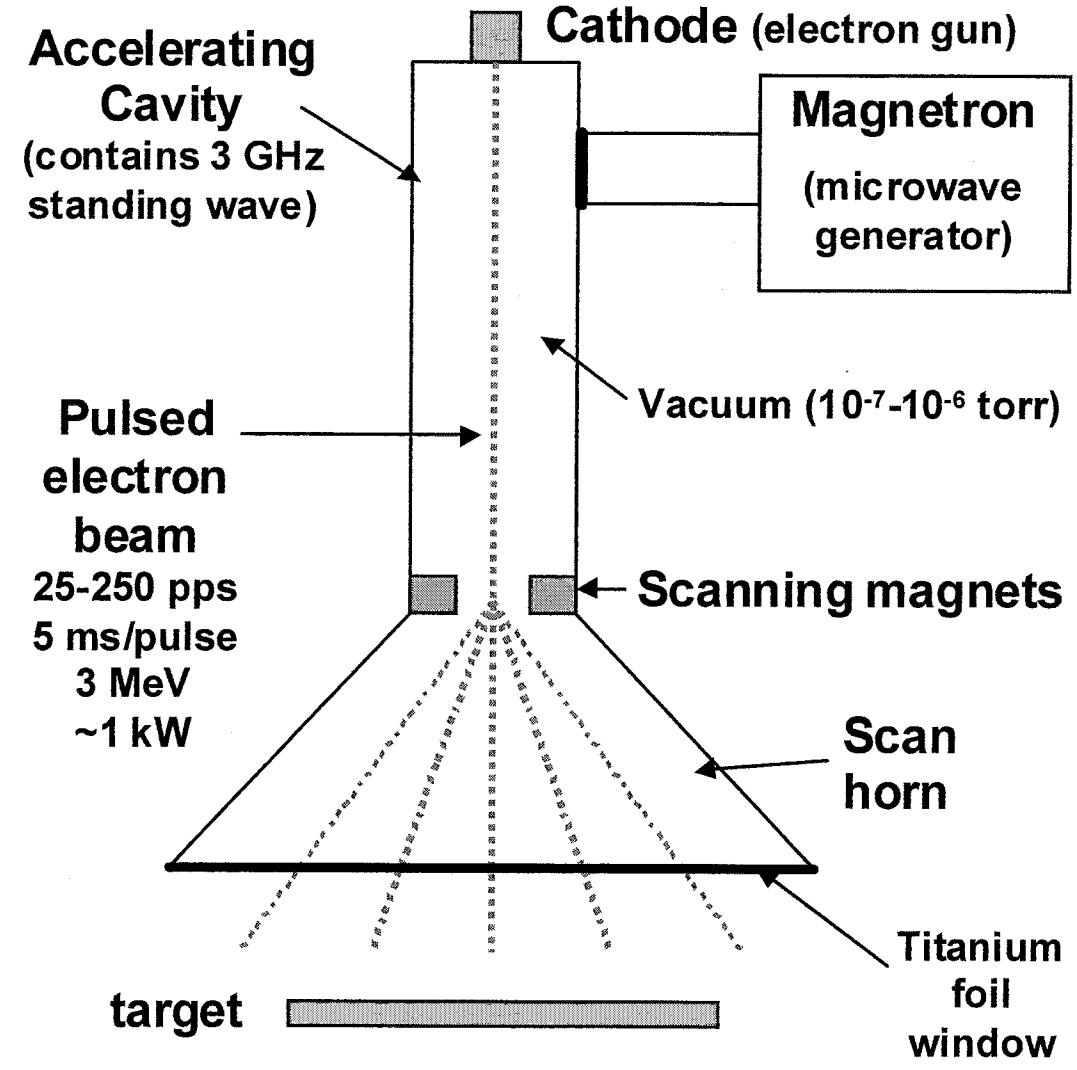


Thermoset Resin Cure



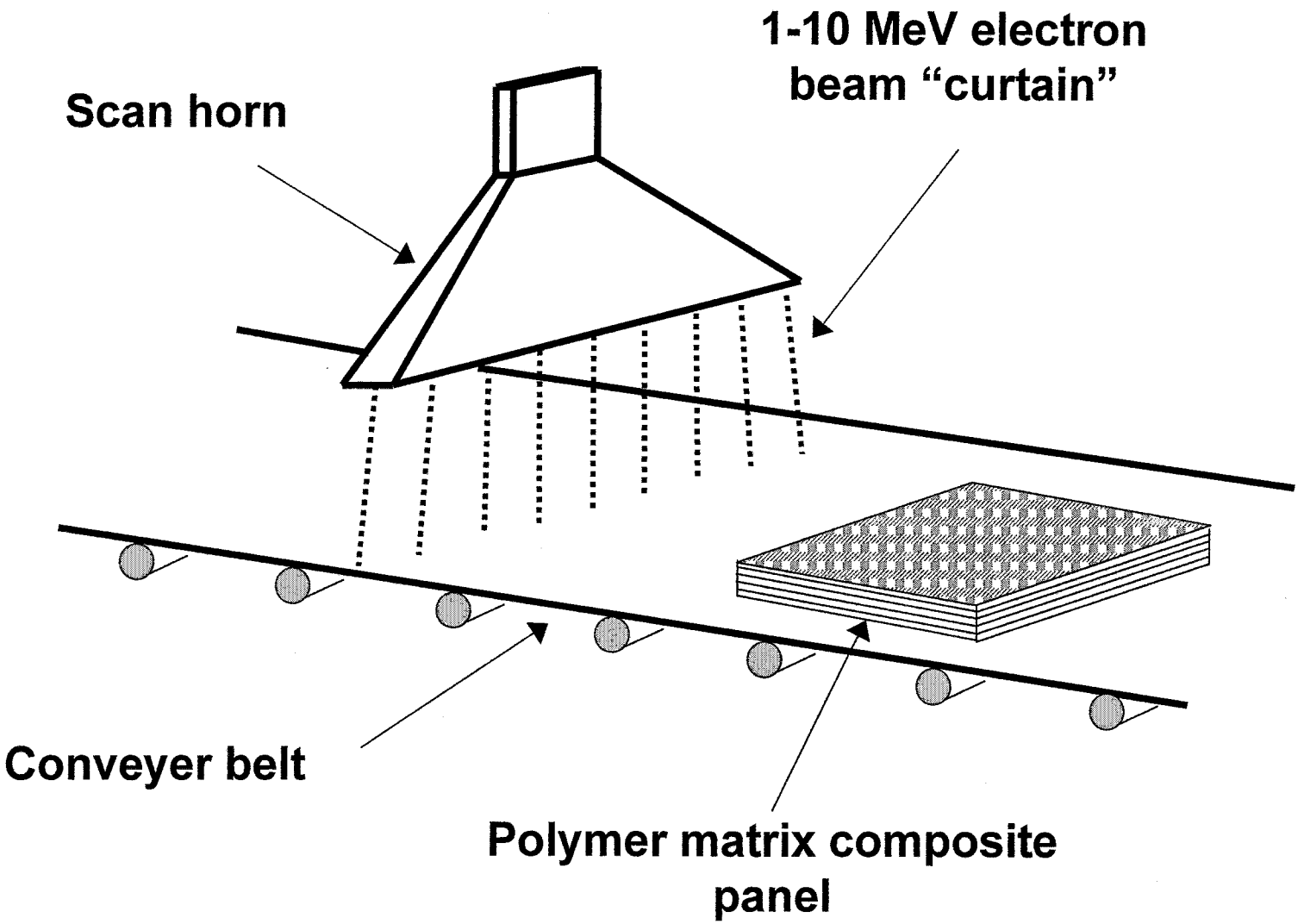
Electron Beam Accelerator

pulsed "Linac" type



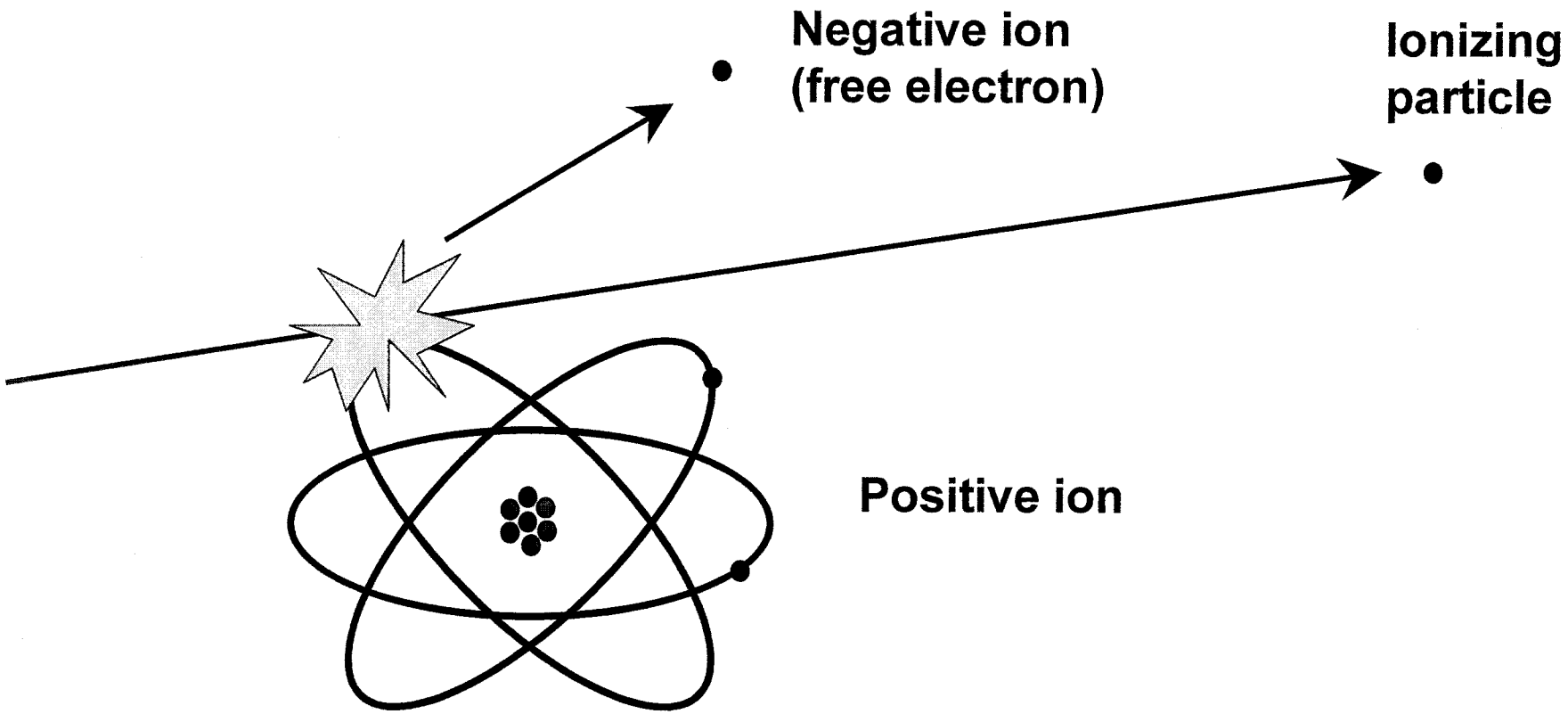
E-beam Curing of Composites

Typical Process Configuration



Ionizing Radiation

Beta particles (electrons)



Free Radical Polymerization

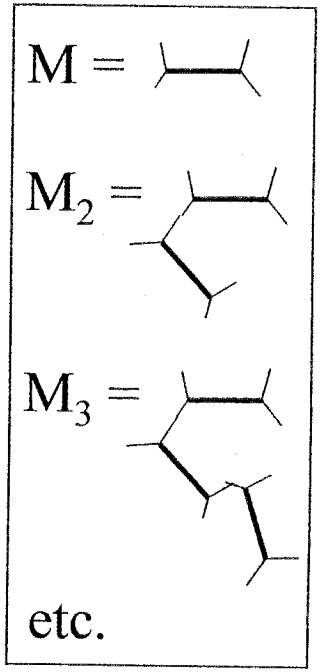
A high energy electron beam creates free radicals, thus initiating the polymerization reaction.

Initiation $M \xrightarrow{e^-} M^* \longrightarrow M\bullet$

monomer — **excited state** — **Free radical**

Propagation $M\bullet + M \longrightarrow MM\bullet \ (= M_2\bullet)$

$M_n\bullet + M \longrightarrow M_{n+1}\bullet$



Termination $M_n\bullet + M_m\bullet \longrightarrow M_{n+m}$ or $M_n + M_m$

E-beam Curing Chemistries

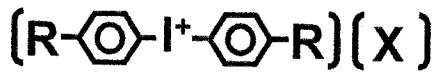
Vinyl Based Systems via Free Radical Cure Mechanism

- **Urethane Acrylates**
- **Silicone Acrylates**
- **Polyester Acrylates**
- **Acrylic Oligomers**
- **Acrylated and Methacrylated Epoxies**

Epoxy Based Systems via Cationic Cure Mechanism

- **Mostly epoxies like Glycidyl Ether of Bisphenol A, plus cationic initiator**

- **Photoinitiator (diaryliodonium or triarylsulfonium salts of weak bases)**



New Uses for E-beam Curable Polymers

- Resins for composite materials

- Adhesive bonding
  - composite / composite
  - composite / metal

E-beam R&D, as it applies to composite materials, is largely focused on developing and improving e-beam curable resins.

E-beam Resin Development History

United States

- Early work (early 1990s)
  - radical initiated systems : acrylates, epoxy acrylates
- Recent work (mid - late 1990s)
  - cationic-initiated epoxy systems (bulk of work)
  - some work on cyanate esters

Europe

- Aerospatiale (France) first introduced acrylate e-beam resins; also worked with epoxy-acrylates and BMI
- Proel Tecnologie (Italy): acrylates, epoxy, BMI

E-Beam Composite Curing R&D

- Aerospatiale (France) : Late 1970's - filament wound rocket motor casings
  - reduce manufacturing costs
  - increase cure rate
  - ability to manufacture large parts

- U.S. : 1990's - various initiatives
  - DARPA / AFRL program (mid 90's)
  - DOE CRADA (mid 90's)
  - many SBIR and other smaller programs
  - DOE CRADA #2; SERDP program (ARL) (1999-)

Advantages of E-beam Curing
(compared to thermal curing)

- **Room temperature curing**
- **Fast (cure in minutes)**
- **Large objects (wings, ship hull)**
- **Complex curvature possible**
- **Net shape / dimensional control**
- **Reduced / no residual stresses**
- **Co-curing of dissimilar materials**
- **Low cost tooling (wood, plastic)**
- **Reduced power consumption (~90%)**
- **Unlimited shelf life**
- **Low emissions**
- **Selective area curing**
- **Assembly curing**
- **Ability to embed and co-cure heat sensitive objects**

Is E-beam Technology New??

NO!

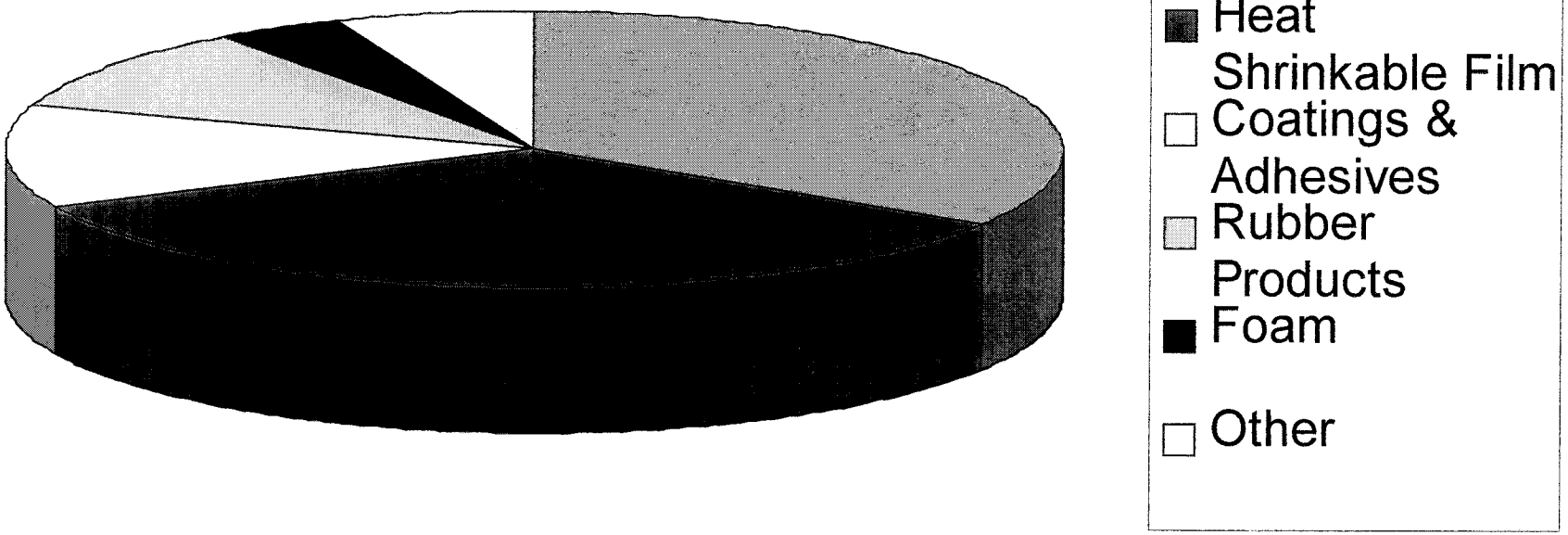
(yes, as applied to composites)

Current Industrial Uses of Electron Beam Irradiation

- Medical sterilization and waste disinfection
- Food treatment (cold pasteurization)
- Sterilization of food packaging
- Bioburden reduction of consumer goods
- Degradation of toxic wastes
- Sanitization of sewage and waste-water
- Depolymerization (cellulose, Teflon powders)
- Coloration of glass and gemstones
- Polymer modification

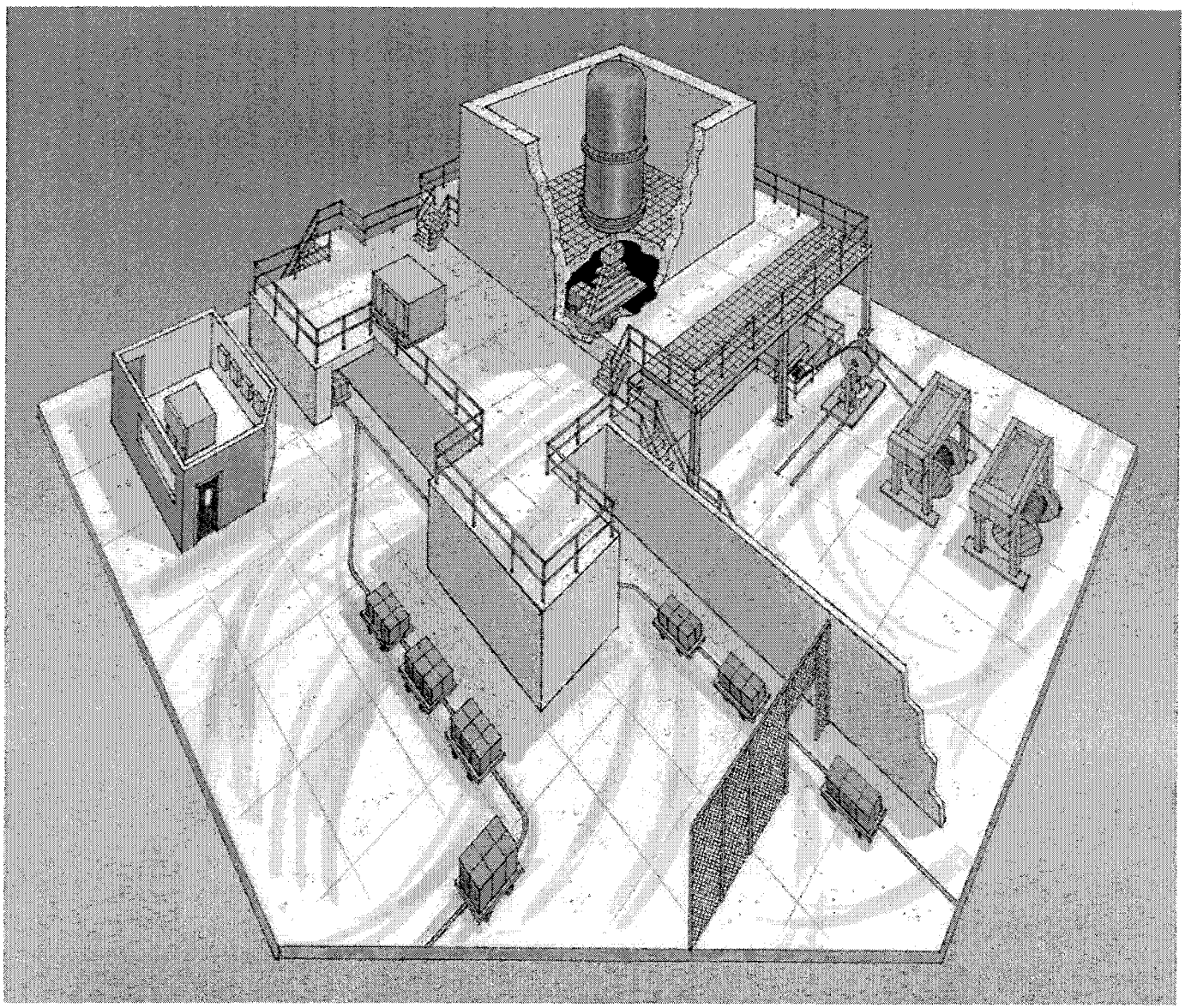
Commerical Uses of Radiation Processing (for polymer modification only)

~ 600 accelerators worldwide



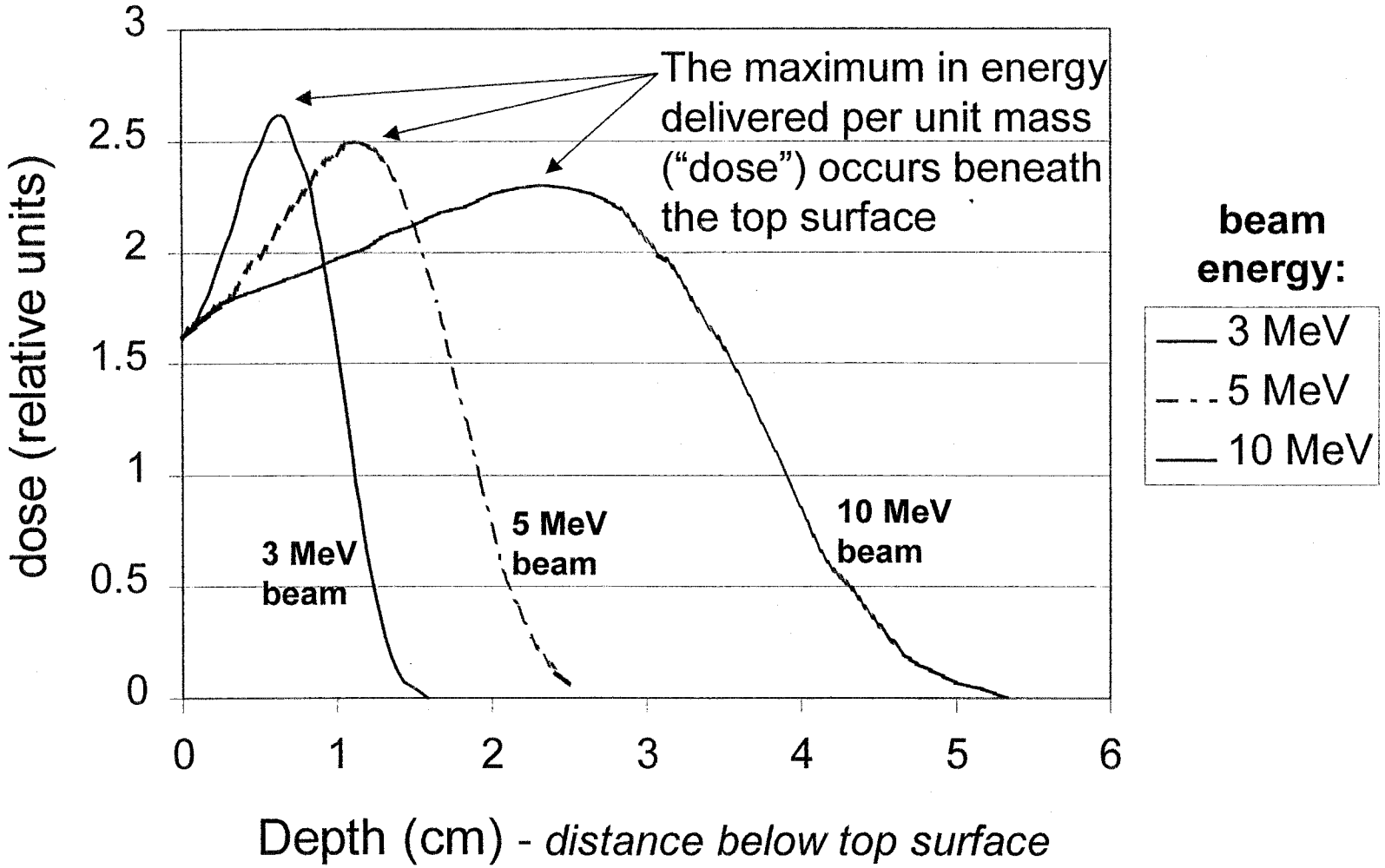
source: Eberle, C., C. Janke, L. Klett, G. Wren, "Radiation Curing of Composite Tutorial," Oak Ridge National Laboratory, April 19, 1999, p.23.

Commercial E-beam Facility Layout



Courtesy E-BEAM Services, Inc., Lebanon, Ohio

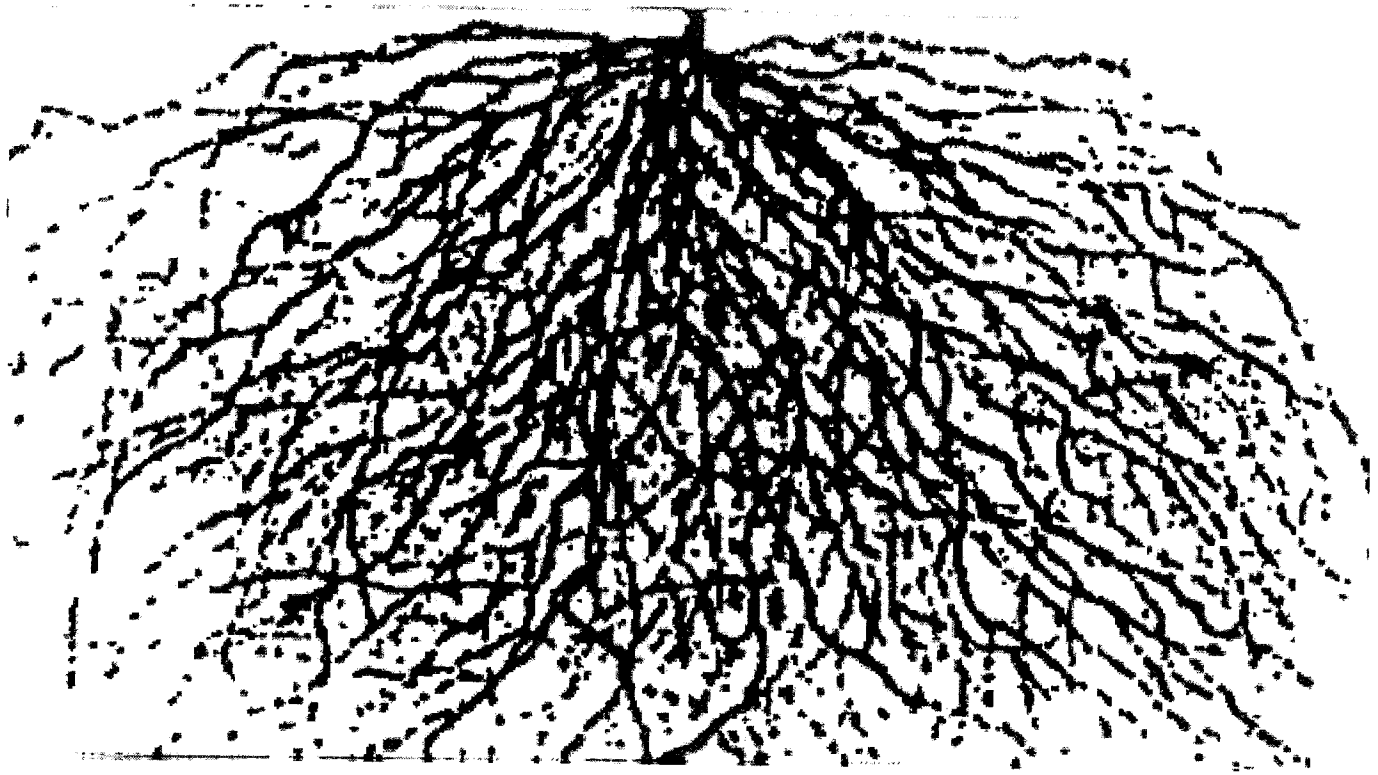
Interesting phenomenon with e-beam curing



From EDMULT Program, see ASTM Standard 1649, "Standard Practice for Dosimetry in an Electron Beam Facility for Radiation Processing at Energies Between 300 keV and 25 MeV"; data given for electron beam in polystyrene.

Electron Scattering

Discharge traces of 3 MeV electrons in a plate of polymethylmethacrylate



Nikola Getoff "Radiation-Induced Degradation of Water Pollutants - State of the Art," ***Radiat. Phys. Chem.,*** Vol. 47 No 4 pp 581-593 1996

Who is interested in e-beam curing of composites?

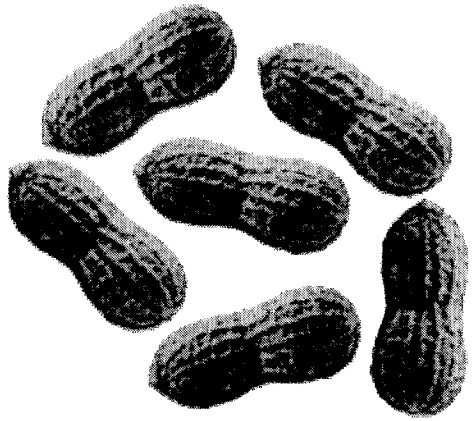
- Largely aerospace / defense industry (automotive too)
- Primary motivation - reduce the cost of manufacturing composite materials!
- Secondary motivations:
  - design flexibility
  - large structures
- Show Video: Affordable Polymer Composite Structures program **(1994-1998)**

Are we ready to fly on composite airplanes that have been cured with e-beams ???

NOT YET

In a nut shell ….

Properties of e-beam cured composites	$\neq$	**Properties of thermally cured composites**



(at least for aerospace applications : require high strength properties at high temperature)

Motivation for Establishing a Basic Research Facility

- Several basic material and processing issues remain to be resolved[1]
- Research-level facilities are needed
- Current facilities are limited to commercial applications.
- Research is best carried out in a university environment
- A university having additional existing composite processing and testing facilities is synergistic.

1. Abrams, F., T. Benson Tolle, "An analysis of e-beam potential in aerospace composite manufacturing", *42 Int. SAMPE Symposium*, May, 1997, pp.548-557.

Laboratory for Research on Electron Beam Curing of Composites

UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE

Mission : To serve as a center for basic research and development to advance the state-of-the-art in electron beam processing of composites.

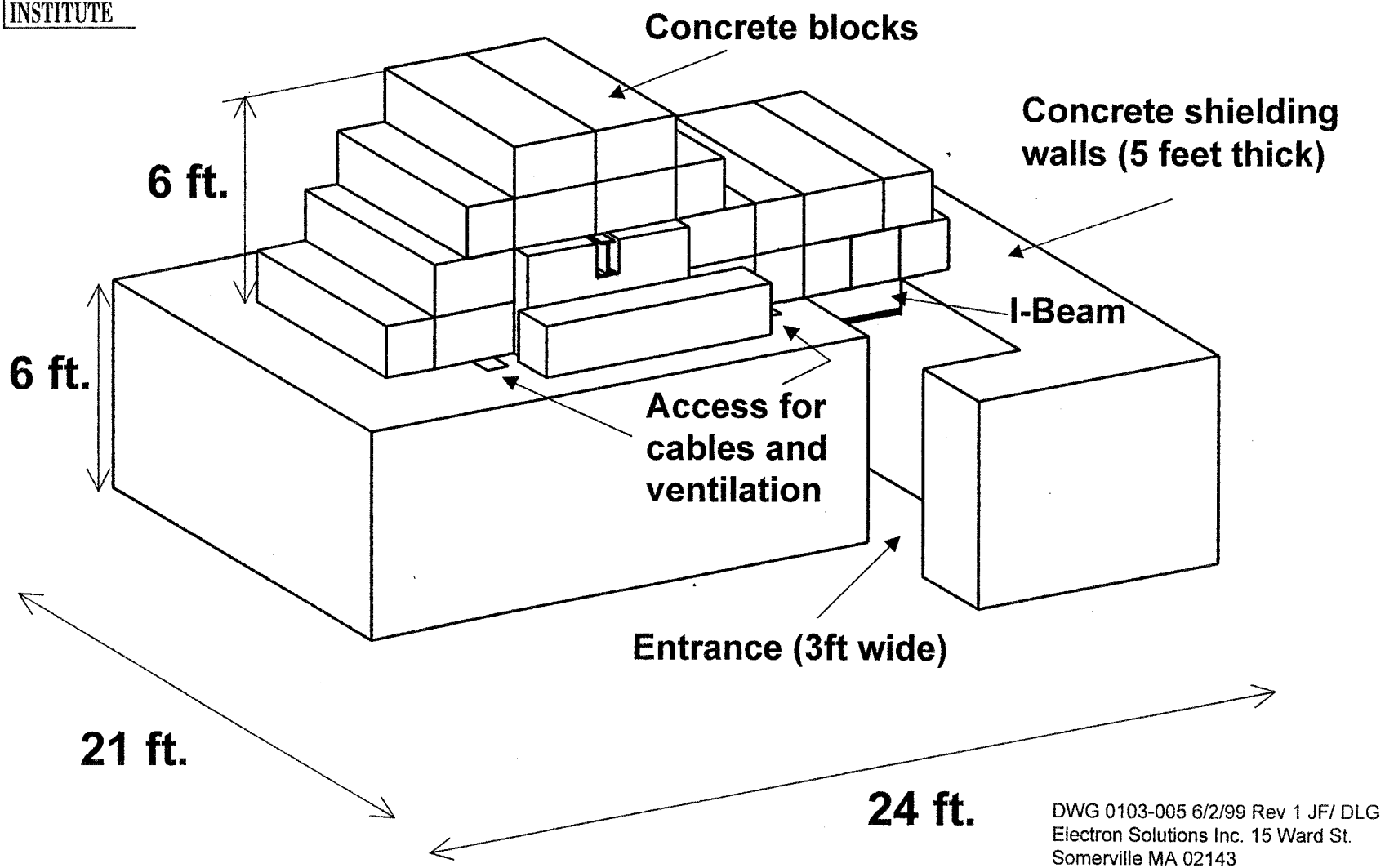
Primary focal areas:

- materials
- processing
- characterization

100% dedicated to research

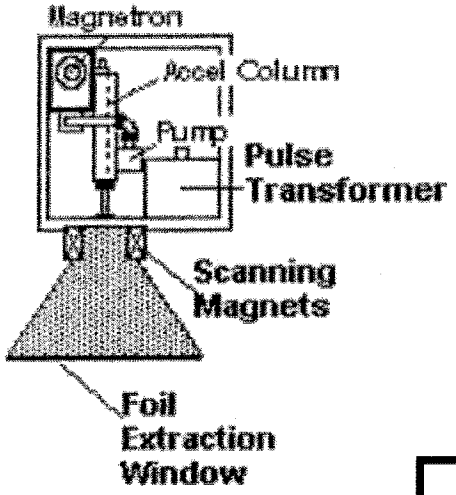
UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE

UDRI Electron Beam Unit

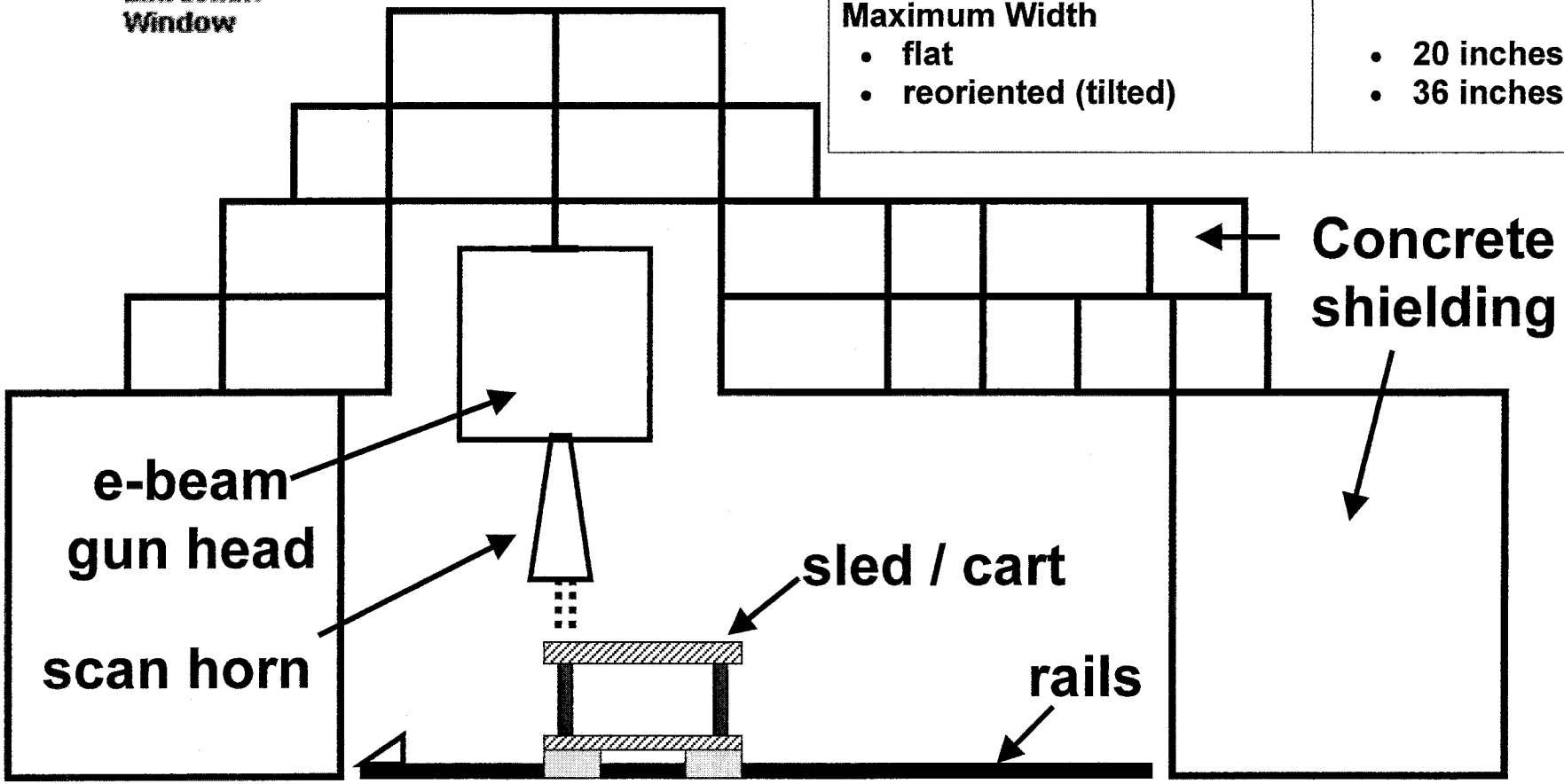


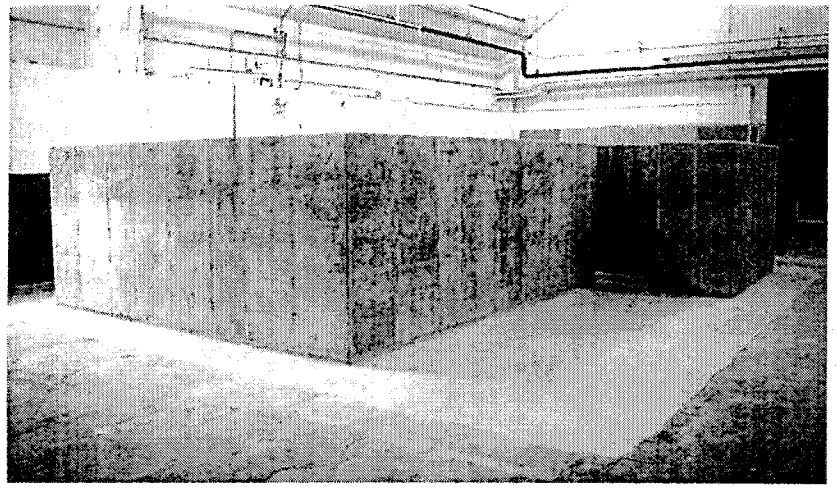
DWG 0103-005 6/2/99 Rev 1 JF/ DLG
Electron Solutions Inc. 15 Ward St.
Somerville MA 02143

System Details

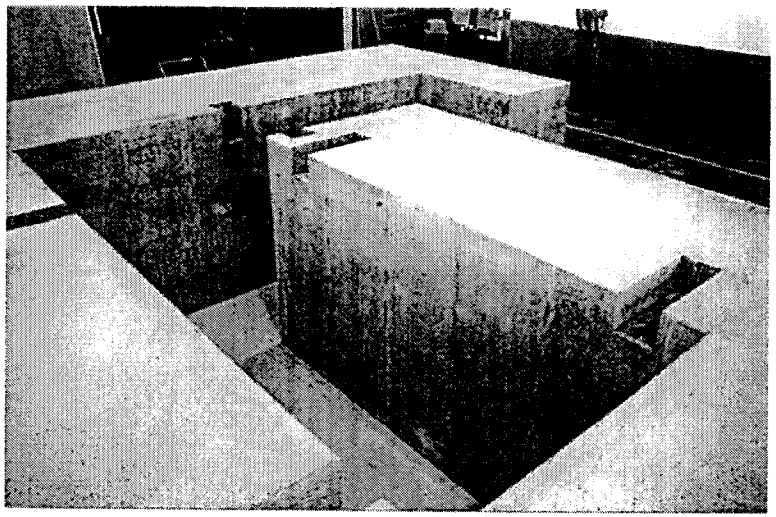


Beam Energy	3.0 MeV
Beam Power	1.0kW
EB Gun Type	S-Band RF Linac
Max. Composite Thickness • single-sided • double-sided	 • 0.25 inches • 0.45 inches
Maximum Width • flat • reoriented (tilted)	 • 20 inches • 36 inches

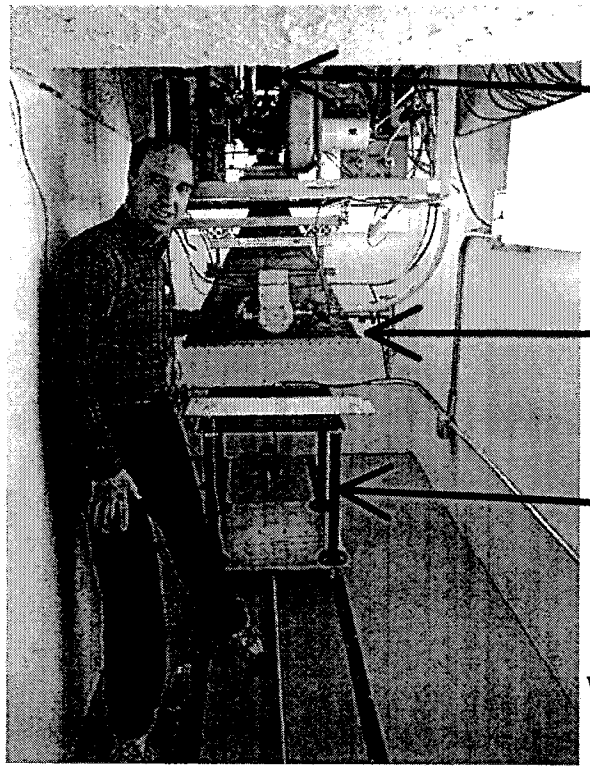




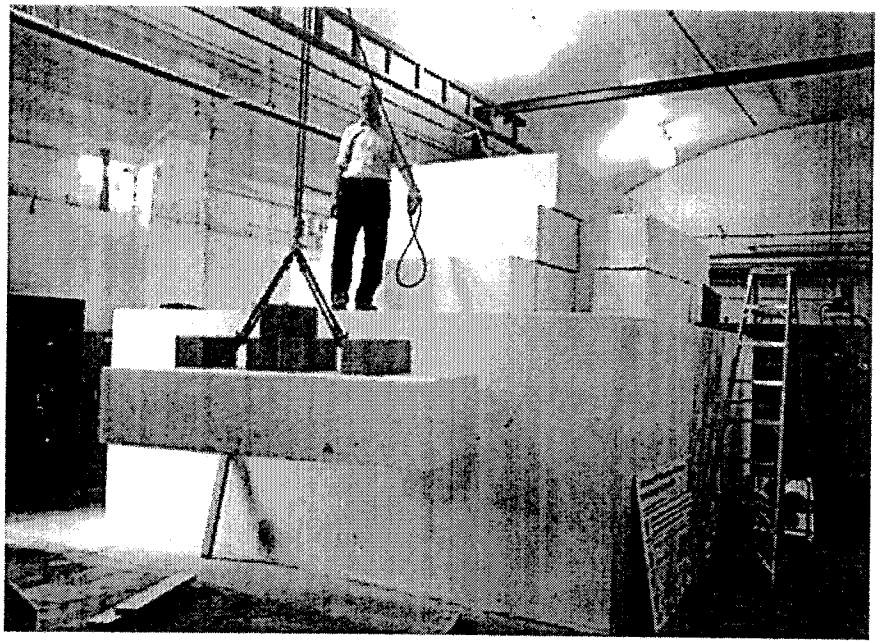
E-beam vault, under construction (Jan. 2000)



Overhead view of vault interior

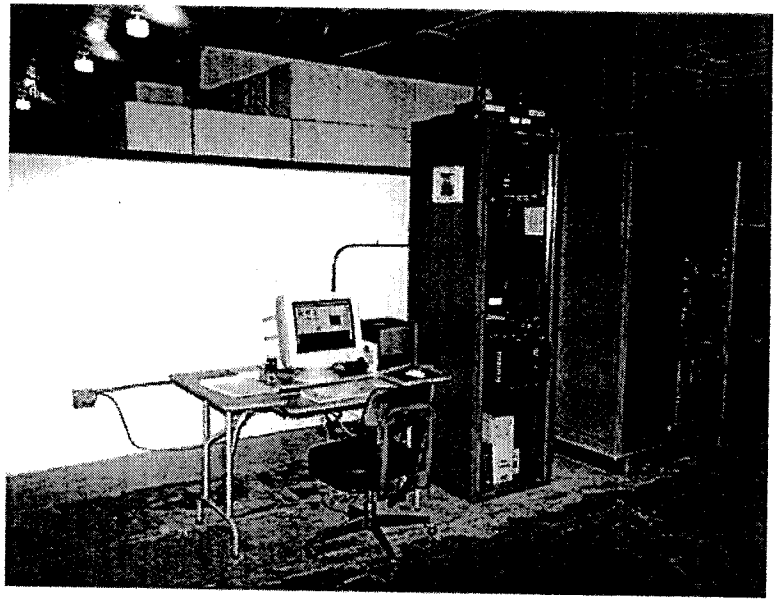


Vault Interior, April 2000



Loading the ceiling blocks, after installing e-beam head and electronics (April 2000)

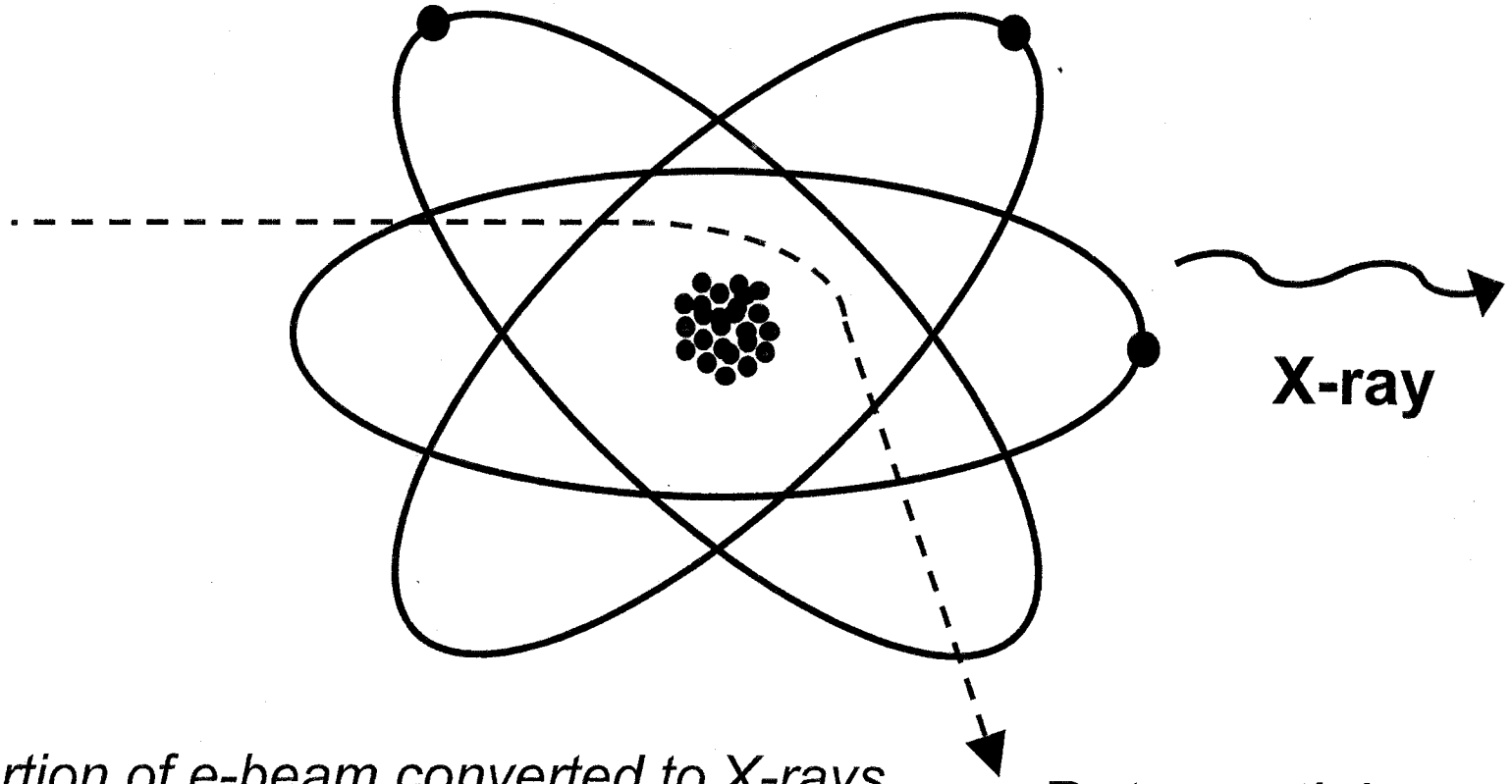
Control Area



machine in operation
April-May 2000

Why so much concrete?

X-ray Production: "Bremsstrahlung radiation"



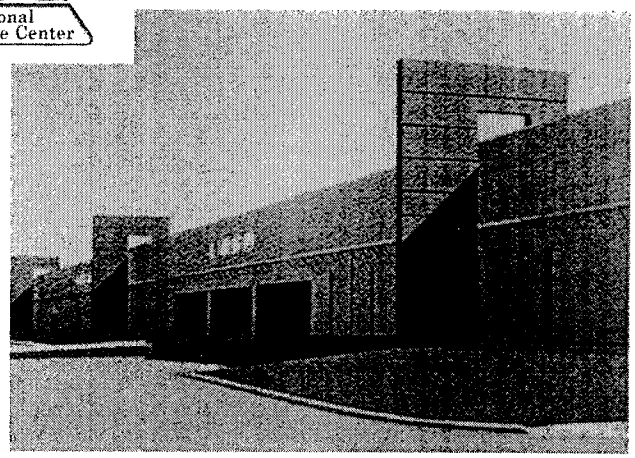
- *portion of e-beam converted to X-rays*
- *X-rays are highly penetrating*
- *therefore require substantial shielding*

"Radiation" and "Radioactive" Should Not be Confused

- Radiation is a term used to describe energy transport
  - **sunshine**
  - **radio waves**
  - **X-rays**
  - **electron beam**
- Radioactive is a term used to describe a substance that continually emits radiation
  - **radon**
  - **cobalt**
  - **tritium**

Facility Location

NCC
National Composite Center



Kettering, Ohio
10 minute drive from UD campus

Sponsors

Air Force Office of Scientific Research (AFOSR)

Air Force Research Laboratory (AFRL)

UDRI
UNIVERSITY of DAYTON RESEARCH INSTITUTE

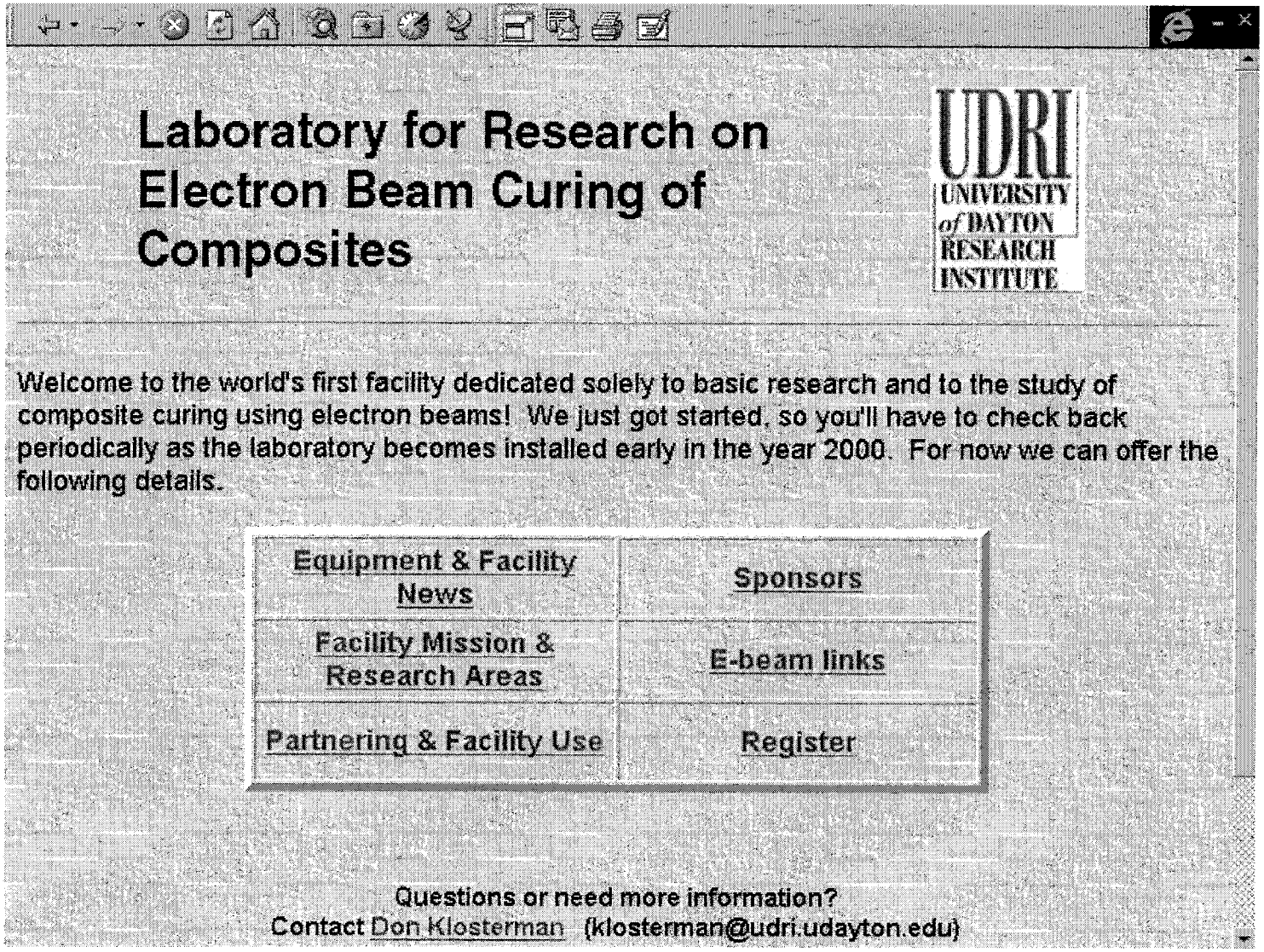
Ohio Board of Regents

A Unique Facility

100% dedicated to research

- Custom-designed for composite study
- Ability to easily vary dose, rate, and XY scan pattern
- Instrumented with dedicated in-situ analytical equipment
- Open to operation by individual researchers
- Comprehensive polymer and composite analysis and testing labs available
- Centralized knowledge base
- Two nearby larger-scale E-beam facilities

Web Site
www.udri.udayton.edu/ebeam



STUDY OF THE MAGNETOSTRICTIVE EFFECT

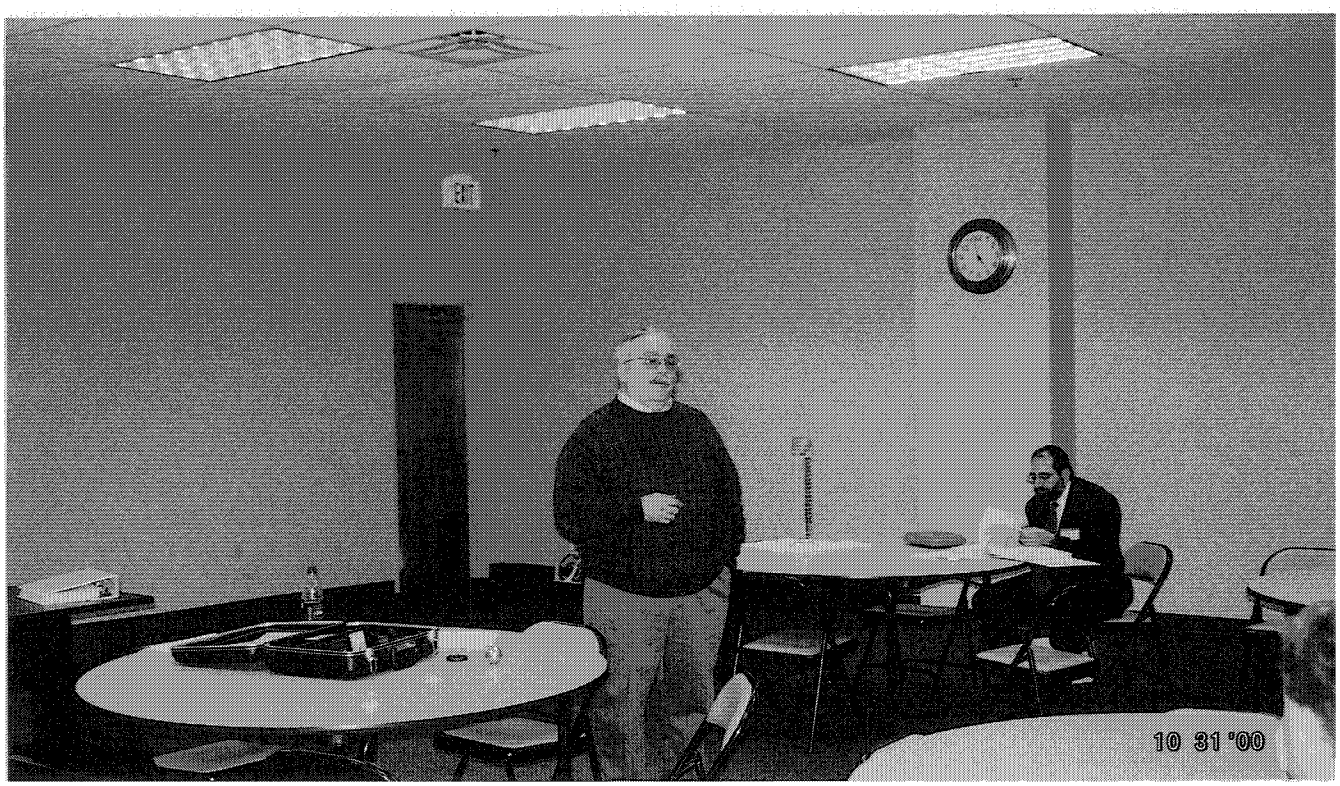
John Marshall

School of Applied Science
University of Southern Maine
Gorham, Maine 04038

Telephone: 207-780-5447
e-mail jmarshall@usm.maine.edu

Biography:

Dr John A Marshall is the Internship Coordinator for the Department of Technology at the University of Southern Maine His areas of specialization include Power and Energy Processing, Electronic Control Systems, Plant Layout /Material Handling, and Industrial Distribution



Study of the Magnetostrictive Effect

John Marshall, Ph.D.
School of Applied Science
University of Southern Maine
Gorham, ME 04038

Abstract:

Magnetostriction is an unusual property in which a material actually changes its shape during the application of a magnetic field. J.P. Joule using nickel first discovered this phenomenon in 1842. Subsequently cobalt, iron and alloys of these materials were found to show a significant magnetostrictive effect with strains of about 50 parts per million (PPM). Applications for this material property began very slowly due to the extreme temperature and cost limitations.

Due to recent advancements in this technology, transducers and actuators that utilize the magnetostriction principle are becoming very popular in cutting-edge motion control automation. These positioning sensors are replacing older, less reliable motion feedback devices. Magnetostrictive sensors are being implemented in a variety of industrial equipment such as injection molding machines, hydraulic presses, sawmills and many different forms of robotic applications.

Key Words: Resolution, Hysteresis, Repeatability, Waveguide, Input & Output Signal.

Prerequisite Knowledge: Basic knowledge of magnetism and an appreciation for accurate positioning control.

Objective: To observe and understand the concept of magnetostriction and to gain an appreciation for the important contributions that this material technology is making to automation engineering.

Equipment and Materials:

Magnetostrictive waveguide positioning sensor demonstrator unit or components needed to demonstrate this experiment are available from MTS Systems Corporation (www.temposonics.com).

Introduction:

Magnetostrictive materials have as a property the ability to convert magnetic energy into mechanical energy and vice versa. As a magnetostrictive material is magnetized, it strains, or exhibits a change in length accompanied by an inverse change in girth. Conversely, if an external force is applied causing a strain, the materials magnetic state changes. This coupling between magnetic and mechanical energies is the transduction capability that allows a magenetostrictive material to be used in both actuation and sensing devices.

One of the first practical applications of magnetostriction was its use in SONAR devices in echolocation during the Second World War. Another early application included torque sensing and these applications are as important today as they were then.

Procedure:

The magnetostrictive waveguide positioning sensor demonstrator unit requires 110VAC as a power supply. After turning the unit on, observe the red digital measurement readout that can be incremented in either millimeters or in inches.

Notice the inclusion of two position magnets that will be "triggering" the sensing element. The flat magnetic ring would be utilized on a solid object such as an injection mold housing, while the buoyant metallic "donut" would be used to sense a fluid level.

The waveguide is the long transducer tube that extends from the head of the sensing element. One magnetic field is generated from a current pulse that is launched along a wire inside the waveguide. A second magnetic field comes from the moving position magnet, which passes along the outside of the transducer tube.

The interaction between these two magnetic fields produces a strain pulse that travels at sonic speed along the waveguide, until the pulse is detected at the head of the transducer. The position of the moving magnet is precisely determined by measuring the elapsed time between the launching of the electronic pulse and the arrival of the strain pulse. As a result, accurate non-contact position sensing is achieved with absolutely no wear to any of the sensing elements.

Turn the demonstrator unit on and select either millimeters or inches. Slide one of the positioning magnets onto the transducer tube and observe the readout. Simulate the linear movement of the object or the increasing / decreasing level of fluid in a container and observe the digital readout. Using a ruler as a confirmation tool, place it next to the transducer tube and compare the readout to the actual distance between the positioning magnet and the locking shaft ring.

The locking shaft ring is held in place with a small set screw. If the actual distance varies from the displayed readout, you may need to calibrate or adjust the shaft ring. This is easily accomplished by loosening the set screw, and adjusting the shaft ring to the linear point when the readout matches the ruler's measurement. Gently tightening the set screw will complete the unit's calibration.

Repeat the motion simulations described above and notice how accurate and repeatable the positioning is being sensed and reported. Unlike traditional mechanical limit switches or reed switches, this dependable magnetostricitive transducer accomplishes the goal of proximity sensing without the use of contacting components.

Comments:

Industrial applications for these magnetostrictive positioning sensors are becoming more numerous each day. They are being utilized on many different types of production equipment such multiple axis injection molding machines where they monitor mold closures. These devices are also replacing traditional contact sensors in rugged applications such as sawmills and presses. In these applications, the magnetostrictive sensors are reporting the position of high-pressure hydraulic cylinders that inherently generate high levels of shock and vibration.

NASA has pioneered several new applications for magnetostrictive actuators designed to generate motion at cryogenic temperatures. The reason for choosing a magnetostrictive (instead of, say, a piezoelectric) actuator to obtain small increments of motion is that magnetostrictive actuators function throughout the desired temperature range and even work better as temperature decreases, whereas piezoelectric actuators tend to become inoperable in cryogenic environments.

One of NASA's devices is a magnetostrictively actuated pump that has been developed to satisfy a need for a small, low-pressure, high-flow-rate fluid pump that contains few moving parts and can run reliably for long periods without maintenance. The pump could be used, for example, to circulate water in the portable life-support system worn by a firefighter or a chemical worker or in any setting where reliability is important and maintenance is difficult. The pump is designed primarily for water as the pumped fluid, but it could also be used with other fluids, including cryogenic ones.

Another NASA innovation is a magnetostrictive valve for remotely controlling a flow of liquid helium. The actuator in this valve is a magnetostrictive device surrounded by a solenoid drive coil that generates the magnetic field needed for actuation.

The magnetostrictive filter-wheel drive is an unusual NASA mechanism that rotates an optical filter wheel for a high-performance infrared camera or telescope. This drive could be operated at any temperature from ambient down to near absolute zero. Moreover, in comparison with a stepping-motor drive, the magnetostrictive drive is simpler, less expensive, and more reliable.

An "inchworm" linear actuator is also being developed that accomplishes its push/pull movement via a combination of magnetostriction and magnetic clamping. It will move a mass as large as 2 kg along rails, with lengthwise position controllable in increments as small as 50 nm. The actuator could be operated in microgravity or in normal earth gravitation and at any temperature from ambient down to cryogenic. The actuator will be used to position an optical assembly precisely on a long interferometer arm, as a translation stage for a scanning tunneling microscope, and as a translation stage for inspecting integrated-circuit chips.

References:

About MTS (2000) Timeline [On-line], Available:
http://www.levelplus.com/about/timeline.html

Magnetic's Group (2000) Magnetic Materials and Their Applications [On-line], Available:
http://www.enc.hull.ac.uk/AP/magnetics/.../Magnetostriction/magnetostriction.html

NASA Tech Briefs, *Technology Transfer*, National Aeronautics and Space Administration, Washington, DC, August 1999, Vol. 23, No. 8, p. 44 – 48.

NASA Tech Briefs, *Technology Transfer*, National Aeronautics and Space Administration, Washington, DC, December 1999, Vol. 23, No. 12, p. 7b –9b.

Physics (2000) Magnetostriction [On-line], Available:
http://www.physics.hull.ac.uk/magnetics/Research/Facilities/Magnetostriction/magnetostriction.html)

Temposonics Glossary (2000) Technology / Glossary / Magnetostriction [On-line], Available: http://www.mtssensors.com/glossary/glossary2.html

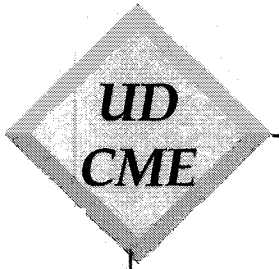
COMPOSITE MATERIALS IN CHEMICAL ENGINEERING

Tony E. Saliba

Professor and Chairman
Chemical and Materials Engineering Department
University of Dayton
Dayton, Ohio 45469-0246

Telephone 937-229-2627
e-mail Tony.Saliba@notes.udayton.edu

Tony E Saliba



Composite Materials In Chemical Engineering

Tony E. Saliba, Ph.D.
Professor and Chairman
Chemical and Materials Engineering
University of Dayton
Dayton, Ohio 45469-0246

National Educators
Workshop '2000

UD
CME

Outline

- **Composite Materials**
- **Role of Chemical Engineers**
- **Critical Need for Education**
- **Potential Solution**
- **Conclusions**

UD CME

Contribution Areas

- Constituent Design
- Processing
- Process and Product Design
- Process Control

National Educators Workshop '2000

UD
CME

Extent of Problem

- Supply and Demand: 500/80
- Growth: 15% in 1986
  400% in 1996
- Sales: $700 millions in 1986
  $2.5 Billion was projected by 1997

UD CME

Justification

- Only One Undergraduate Program
- Graduate Level Education
- 40% of Jobs Are in Fabrication
- Curricula Allow Few Electives
- Shortage of Qualified Engineers

National Educators Workshop '2000

UD CME

Potential Solution

- Topics Introduction in Existing Courses

- Expand Employment Opportunities
- Supply Much Needed Engineers

UD CME

Introductory Class

- Introduction to Composite Materials

- Constituent Materials
- Bridge Building Contest (CME&CIE)

National Educators Workshop '2000

UD CME

Transport Phenomena
I. Fluid Mechanics

- 1. Resin Flow During Autoclave Cure
  - Flow Between Parallel Plates
  - Flow Around Plates and Cylinders
  - Flow Through Porous Media
  - Resin Loss, Compaction Rate

- 2. Other Processes
  - Pultrusion
  - Extrusion
  - RTM

National Educators Workshop '2000

UD CME

Transport Phenomena
II. Heat Transfer

- 1. Thermophysical Properties of Anisotropic Systems
  - Resistance Analogy
  - Volume Average
  - Empirical Formula
  - Transport Properties
- 2. Heat Transfer Codes
  - Modeling Heat Transfer in an Autoclave (Convective BC)
  - Heat Transfer in a Press (Temperature and Heat Flux BC)
  - Heat Generation from Exothermic Chemical Reactions
  - Coupled Heat Transfer and Fluid Flow in an Extruder

UD
CME

Transport Phenomena
III. Mass Transfer

- Diffusion of Water/Solvents in Composites
- Void Nucleation and Growth

UD
CME

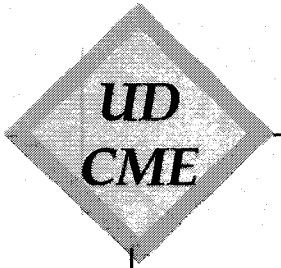
Transport Phenomena Laboratory

- Temperature Distributions Measurement During Composite Cure
- Diffusion Coefficient of Moisture in Composite Materials
- Viscosity Measurement During Cure of Composite Materials
- Apparent Thermal Conductivity of Composites

UD
CME

Kinetics and Reactor Design

- 1. Polymer Kinetics
  - Reaction Mechanisms
  - Available Kinetics Models
- 2. Crystallization Kinetics
  - Avrami Equation
  - Avrami Equation Based Crystallization Models



Unit Operations

- Filament Winding
- Prepreg Layup
- Autoclave Molding
- Injection Molding
- Compression Molding
- Resin Transfer Molding
- Reaction Injection Molding

UD CME

Product and Process Design

- Process Modeling and Optimization
  - Available Codes and limitations
- Material Selection Criteria
  - Geometric Considerations
  - Properties Requirements
  - Cosmetic Requirements
  - Processability/Maintainability
  - Product Quality
  - Cost

UD CME

Product and Process Design

- Design Concepts
  - Cost of Design and Manufacturing
  - Coordination Between Design, Tooling, and Manufacturing
  - Product Quality Assessment and Control
  - Joint Design
  - Design Databases
  - Computer Codes for Design
  - Life-Cycle Analysis

UD CME

Product and Process Design Project

- Justification for Using Composites
- Constituent Materials Selection
- Manufacturing Techniques Chosen
- Meeting Design Requirements
- Quality Assurance
- Modification and Recommendations

UD CME

Process Control Project

- Process Modeling
- Qualitative Process Automation
- Expert System Control
- Expert Model Control

National Educators Workshop '2000

UD CME

Conclusions

- Emerging Technology
- Role of Chemical Engineers
- Critical Need for Exposure
- Implementation of Topics/Case Studies/Projects in Existing Classes

OFF-SITE SCANNING MICROSCOPY OF SILVER-COPPER ALLOYS: FIRST STEPS TO INTERNET-BASED MICROSCOPY

L. Roy Bunnell

Southridge High School
3350 Union Loop Road
Kennewick, WA 99336

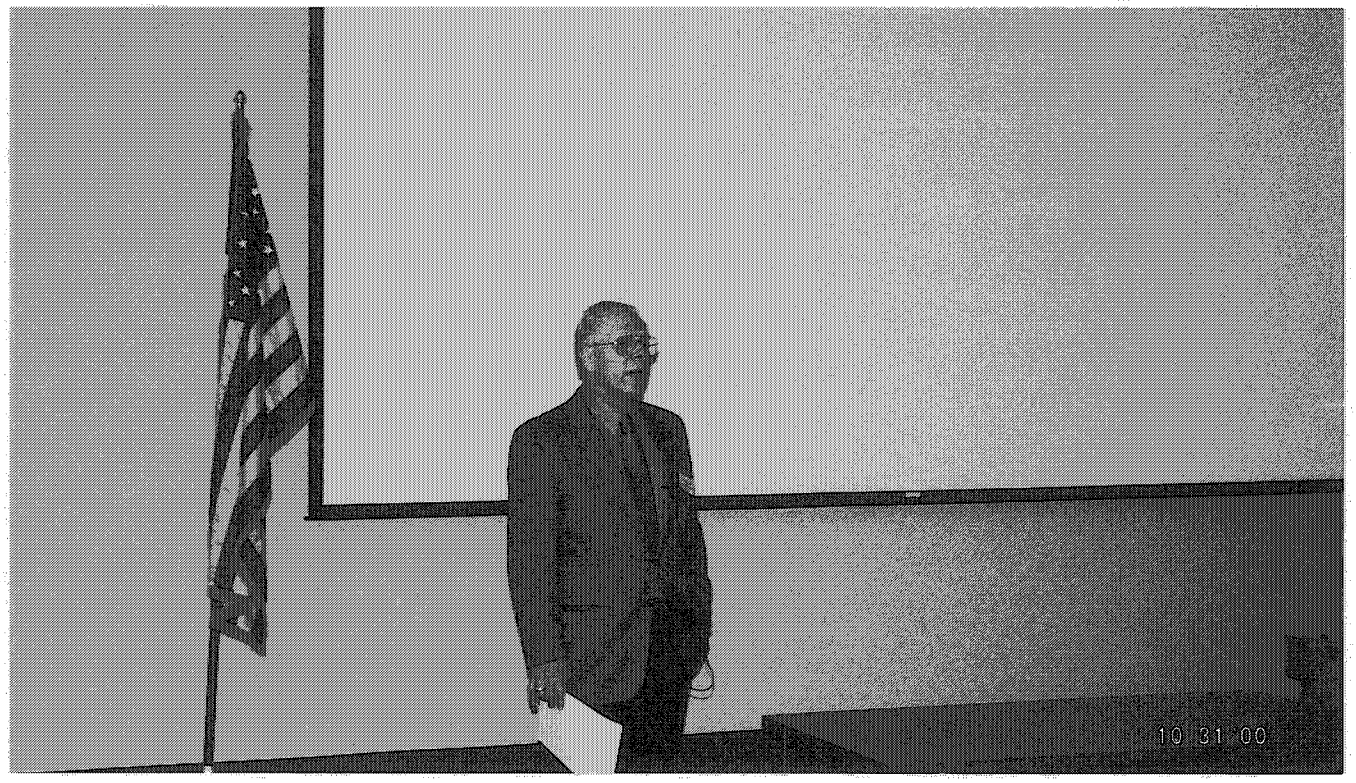
Telephone 509-734-3800
e-mail Bunnro@ksd.org

and

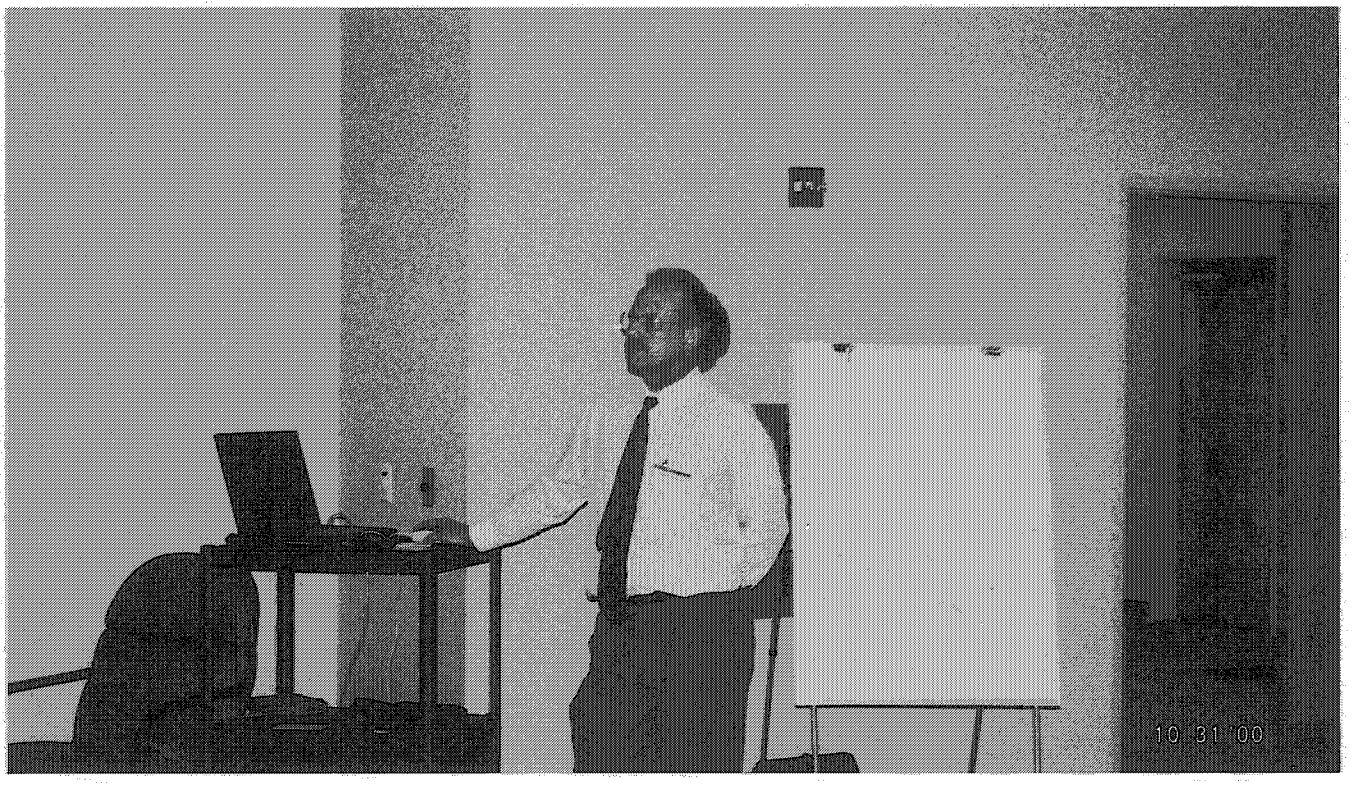
Stephen K. Kennedy

RJ Lee Group, Inc.
350 Hochberg Road
Monroeville, Pennsylvania 15146

Telephone 724-325-1776
e-mail skennedy@rjlg.com



L. Roy Bunnell



Stephen K. Kennedy

Off-Site Scanning Microscopy of Silver-Copper Alloys: First Steps to Internet-Based Microscopy

L. Roy Bunnell
Southridge High School
3350 Union Loop Road
Kennewick, WA 99336
Bunnro@ksd.org

Stephen K. Kennedy
RJ Lee Group, Inc.
350 Hochberg Road
Monroeville, PA 15146
Skennedy@rjlg.com

Key Words: Scanning Electron Microscopy, Precipitation Hardening, Sterling Silver, Silver-Copper Alloys, Work Hardening

Prerequisite Knowledge: Students should understand how precipitation hardening works to increase the apparent hardness and yield strength of alloys. They should have an introduction to phase diagrams, in order to understand the limits of solubility of alloying ingredients and the role of heat treatment in developing a microstructure of fine precipitates to pin dislocations. In a course in Materials Science Technology taught at the high school level, students are exposed to the above concepts as part of preparation for making a sterling silver casting by the lost wax investment casting method.

Objective: The objective of this exercise is to instruct students on how copper affects the hardness of a silver-copper alloy, then to relate this change to microstructure as observed in scanning electron microscope (SEM) images. This was accomplished by preparing three different versions of a material used in the class--sterling silver--at Southridge High School in Kennewick, Washington and to then perform SEM analysis on the specimens at the facilities of RJ Lee Group in Pennsylvania. The resulting photographs and analytical results were transmitted via Internet, to see whether the structures were as expected from the phase diagram.

It is anticipated that in the near future the SEM (as well as other instruments) can be accessed and operated through the Internet. Ultimately, Internet access to expensive instruments makes them a shared resource that will be within the reach of students.

Equipment and Materials: Specimens were prepared using pure (99.97%) silver and oxygen-free copper in wire form. They were melted in an electrically-heated melter, and contained in a graphite crucible to provide a reducing atmosphere.

Introduction: Silver is a reasonably-priced precious metal. It is often used for jewelry, but pure silver is too soft to have the required strength and durability. Alloying silver with 7.5 wt. % copper produces an alloy called sterling silver. This material, when properly heat-treated, has the copper-rich phase in the form of very fine precipitate particles. When the alloy is then cold-worked, the dislocations moving through the structure are pinned in place by the precipitate particles, producing a pronounced work-hardening effect. The work-hardened alloy is hard enough for jewelry and tableware.

The phase diagram below (redrawn from Jacobs and Kilduff) shows the silver-copper system.

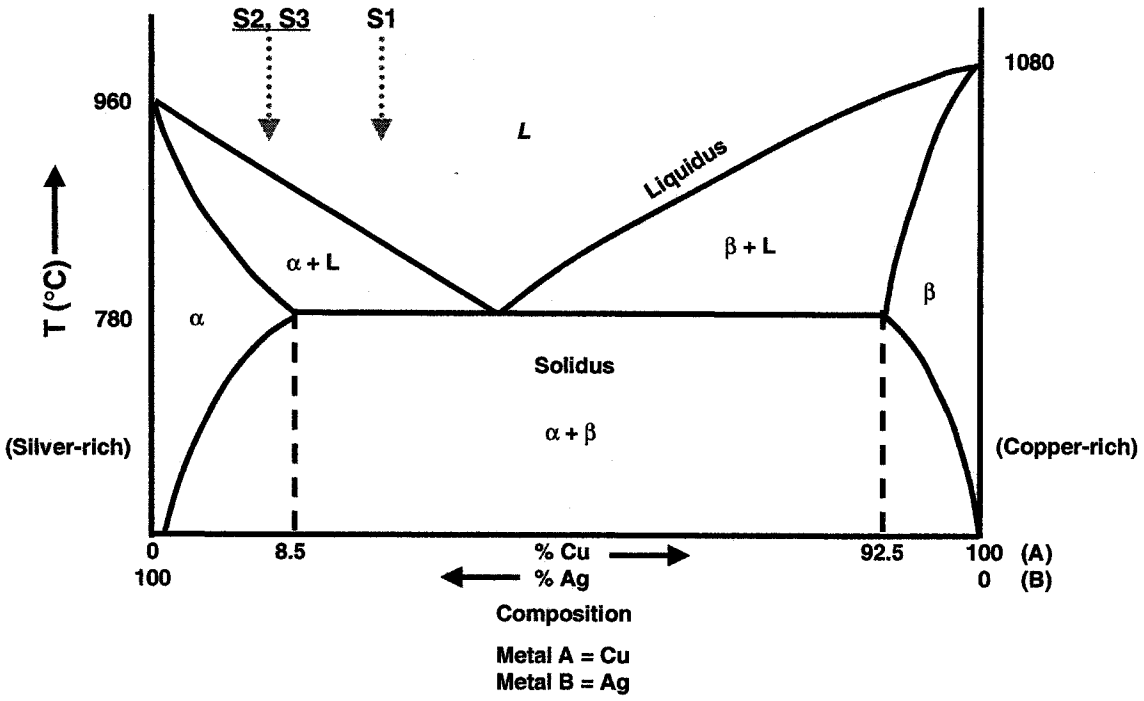


Figure 1. Silver-Copper Phase Diagram showing starting compositions of the three samples.

The system shows typical eutectic behavior, and indicates that when heated silver-copper mixtures will commence melting at 780° C, lower than either copper (1080°C) or silver (960°C). Silver will dissolve into copper as a solid solution to a maximum of 7.5 wt. %. This phase is seen on the right side of the diagram as "beta". Likewise, copper will dissolve into silver to a maximum of 8.5 wt. % seen on the left side of the diagram as "alpha". Slow cooling of a melt of sterling silver composition ($Ag_{92.5}$ $Cu_{7.5}$) should result in a two-phase mixture, composed of silver-rich alpha and copper-rich beta. Sudden cooling of the mixture may not permit the equilibrium amount of each phase to form. Proper heat treatment should result in a structure composed of alpha, containing small, dispersed particles of the beta phase. This is the desired microstructure in jewelry, since many small particles provide the best opportunity for pinning dislocations as they move through the metal crystals during deformation.

Although the average composition of any sample is controlled by the original mix of metals the nature of the phase diagram and the cooling history can result in phases of different composition and internal structure The scanning electron microscope (SEM) can be used to examine the composition and texture The SEM is an imaging and microchemical instrument When an electron beam hits a specimen the electrons can be scattered back out of the specimen The backscattered electrons detected while the beam is rastering over an area will produce an image The number of electrons that are backscattered is a function of the average atomic number of the specimen material In the images produced in this mode areas that are brighter are comprised of heavier material and this image contrast allows different phases to be discriminated Phases richer in silver are brighter than phases richer in copper Backscattered electron (BE) images were saved to document morphology and internal structure

Electrons that are not backscattered can interact with the specimen to produce x rays The energy of an x ray is related to the electronic configuration and the elemental composition can be determined by acquiring and displaying the energy spectrum Peaks in the energy spectrum are related to specific elements and the displayed peaks can be labeled with that element symbol Using an energy dispersive spectrometer (EDS) the elemental composition of phases identified in the backscattered electron image can be characterized It is important to note that volume of the sample that is affected by the electron beam and from which x rays can be generated has a diameter on the order of 2 3 micrometers Features smaller than that will have a mixed spectrum comprising the x rays generated by the feature of interest and those of the matrix

Procedure: Materials used were pure (99 97%) silver purchased as 1 oz coins, and oxygen free copper wire These were melted at 1000° C in a graphite crucible and heat treated as follows

Specimen #1 contained twice the sterling amount of copper (15 wt %) and was slow cooled from melting in order to develop a coarse microstructure showing the rejected excess copper silver phase

Specimen #2 contained the sterling amount of copper and was quenched in water after melting to develop a fine microstructure in which much of the copper is still in solution

Specimen #3 had the sterling silver composition like #2 except that it was quenched from 770° C to produce a supersaturated solution at room temperature Finally the specimen was heated to 300° C for 30 minutes to develop the desired fine microstructure During the final step the hardness of the alloy is reported to double as a result of this structure

The specimens were sent to RJ Lee Group Inc for metallographic preparation and examination by scanning electron microscope (SEM). Each specimen was sectioned using a diamond blade saw and mounted in Lucite The mount was polished using 3 micrometer then 1 micrometer diamond paste Each mount was given a thin coat of carbon to prevent charging while under the electron beam

Each sample was examined at low and high magnification. Each phase observed was also characterized by EDS analysis. Results are below.

Comments: The microstructure of Sample #1, containing twice the sterling amount of copper and slow-cooled, is as shown in **Plates A, B** and **C. Plate A** shows that there are two phases and they display an ordered microstructure. A bright silver-rich (alpha) phase occurs as laths approximately 50 um wide (**Plate B**) and is also interspersed with the darker copper-rich beta phase (**Plate C**).

The structure of Sample #2, of sterling composition and quenched, also shows two recognizable phases. The presence of laths (**Plate D**) indicate that there was sufficient time in the quenching process to form crystals, but that the laths are smaller in width (about 10 um) and there is a smaller amount of the darker phase. **Plate E** shows that the bright phase is the silver-rich alpha phase, and **Plate F** shows that the darker phase is the copper-rich beta phase.

Sample #3 was of sterling composition and heat treated to develop the fine precipitates. **Plate G** shows that the interior (to the left) of the sample has no apparent structure other than an occasional small dark phase. **Plate H** demonstrates that the bright phase is silver-rich and contains a small amount of copper. The exterior rim of the sample (to the right) shows the presence of a second phase. **Plate I** shows the bright phase in the rim to be silver-rich and copper free. **Plate J** shows that the small dark occurrences in the rim are copper that has been oxidized. It appears that the heat treatment has driven the copper out of the silver phase to form discrete copper oxide. **Plate K** is a line scan for copper and shows the decrease in copper in the bright phase from the interior (left) to the exterior (right) of the sample.

This SEM microscopy is the first step in a connection via Internet between students and expensive and specialized instrumentation. The images in this paper will be shared with the students in high-school Materials Science Technology classes. In the near future, it is hoped that high-school students in the classes will have real-time access to this instrumentation.

References:

Jacobs, J. A., and Kilduff, T. F., Engineering Technology: Structure, Properties and Selection, Third Ed., 1997, Prentice-Hall, Pages 258-261.

Plate A

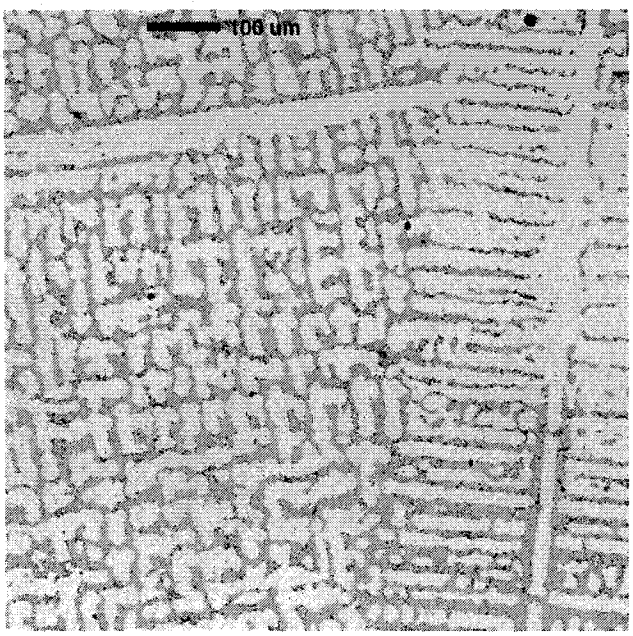


Plate B

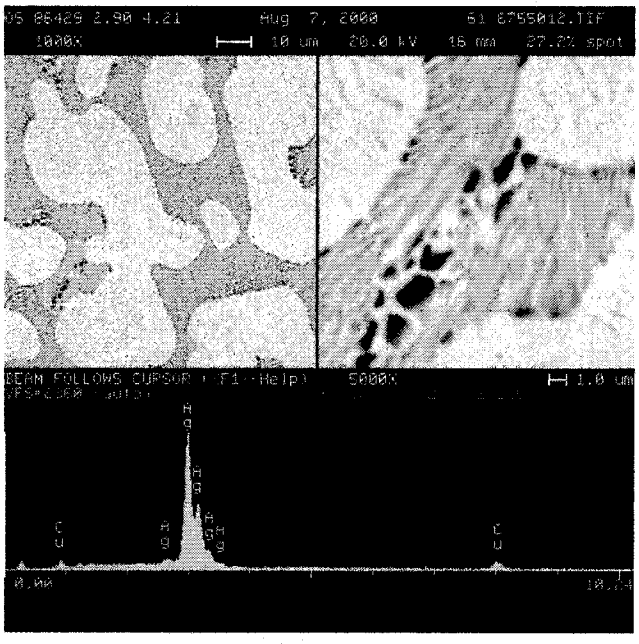


Plate C

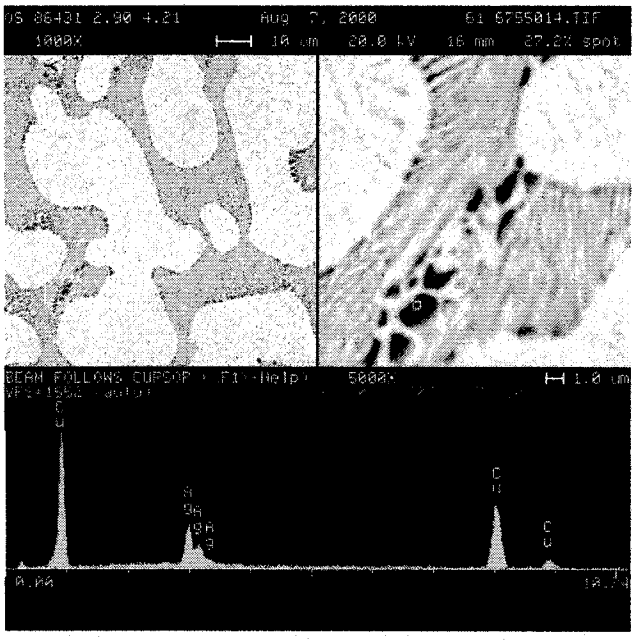


Plate D

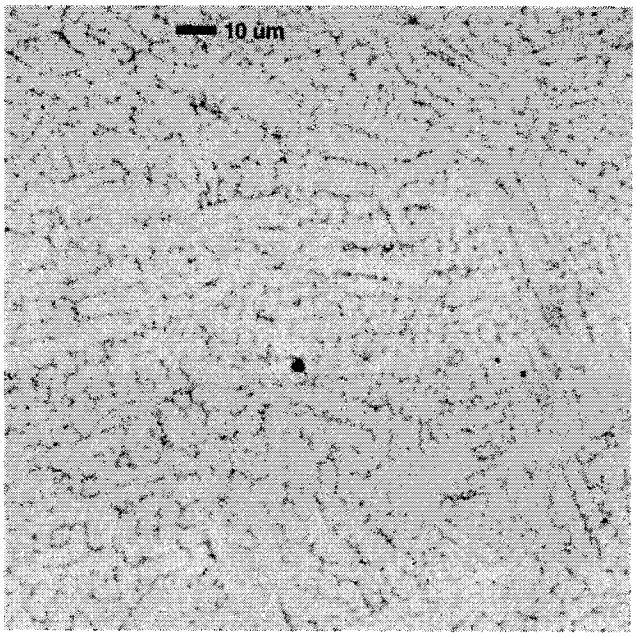


Plate A – BE image of Sample #1 showing the presence of two phases. **Plate B** – BE images and EDS spectrum of Sample #1 showing the bright phase is silver-rich with a small amount of copper. **Plate C** – BE images and EDS spectrum of sample #2 showing the dark phase is copper-rich. **Plate D** – BE image of Sample #2 showing the presence of two phases.

Plate E

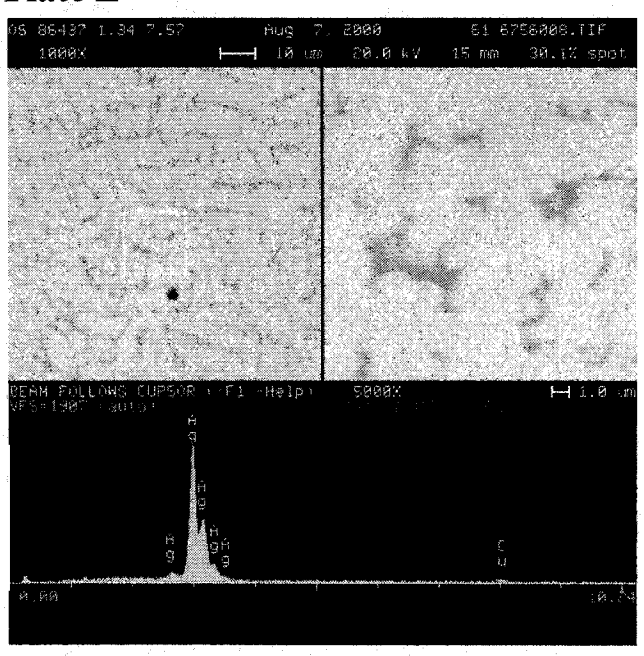


Plate F

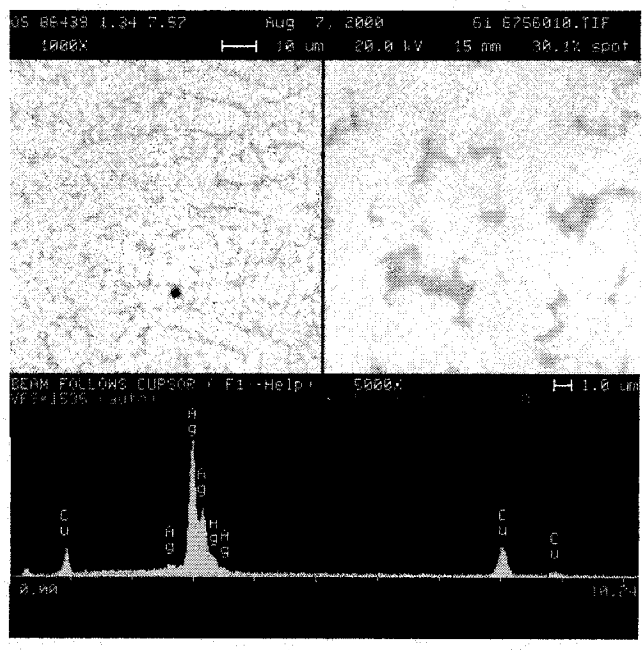


Plate G

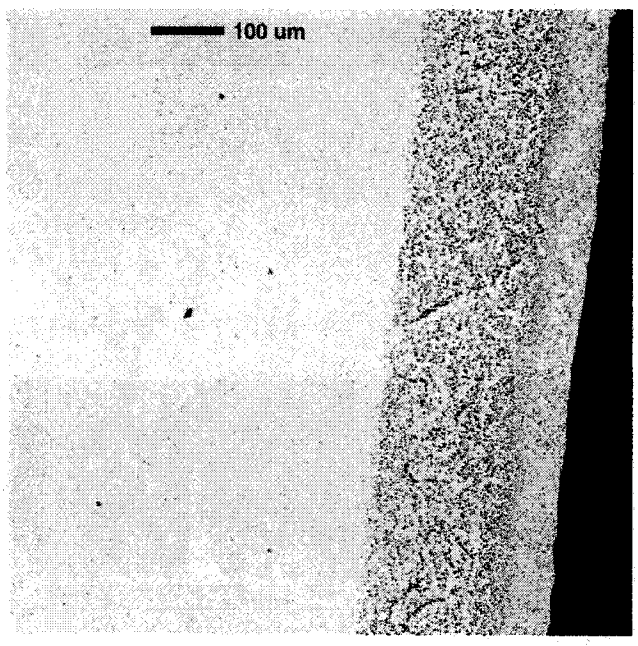


Plate H

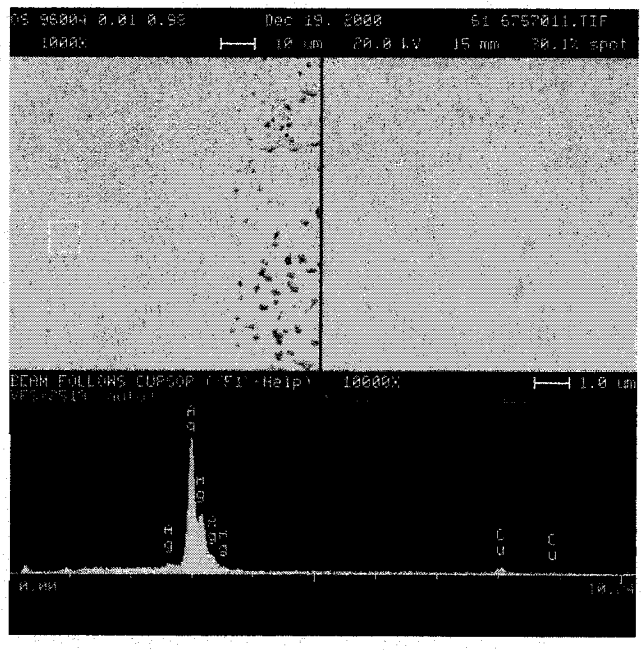


Plate E – BE images and EDS spectrum of Sample #2 showing the bright phase is silver-rich. **Plate F** – BE images and EDS spectrum of Sample #2 showing the darker phase is copper-rich. **Plate G** – BE image showing the interior of Sample #3 (left) to be primarily a bright phase with scattered dark occurrences and the sample exterior (right) to have a 250 um rim with concentrated dark phase occurrences. **Plate H** – BE images and EDS spectrum showing the bright phase in the interior to be silver-rich and containing copper.

Plate I

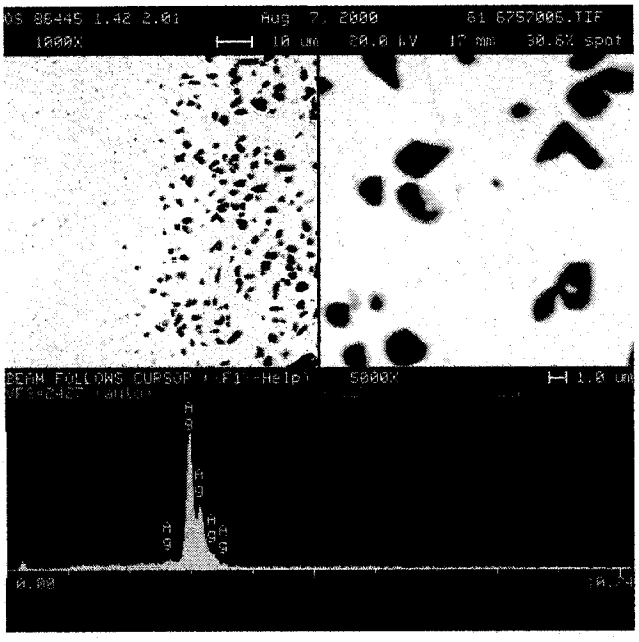


Plate J

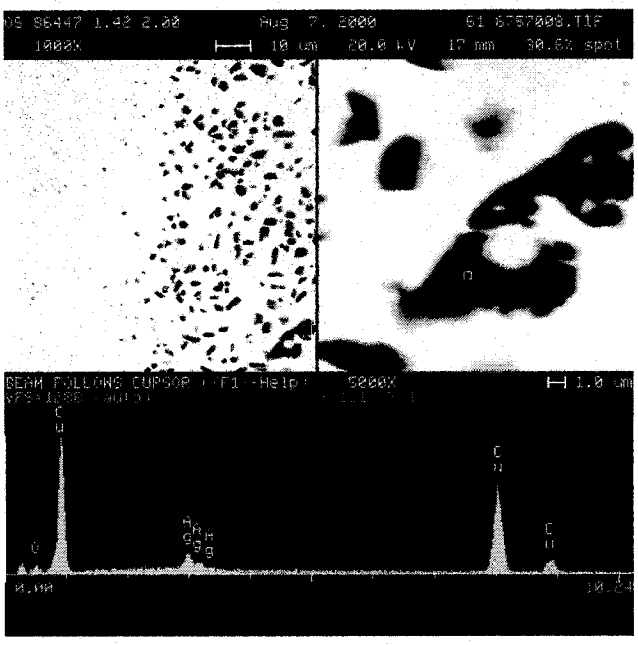


Plate K

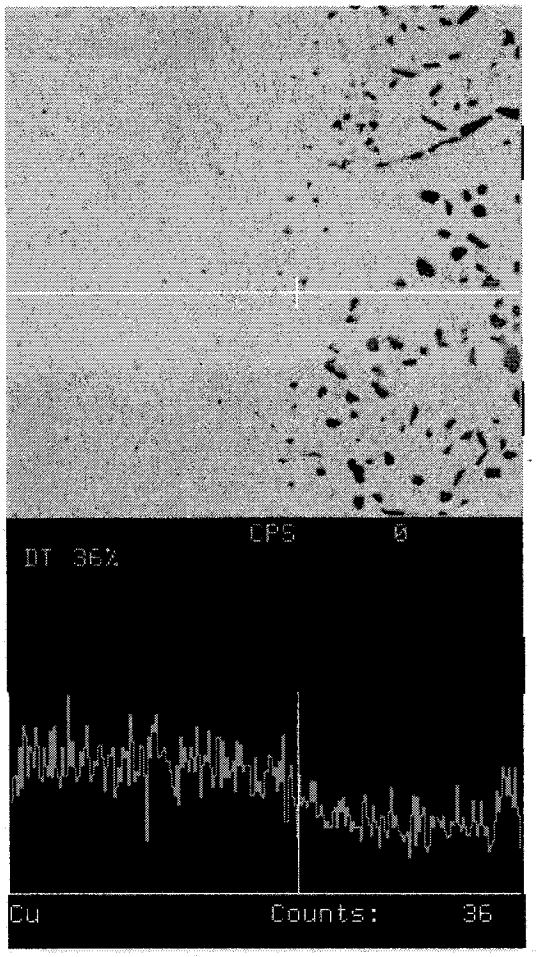


Plate I – BE image and EDS spectrum of Sample #3 showing the bright phase in the rim to be copper-free silver. **Plate J** – BE image and EDS spectrum of Sample #3 showing the dark phase in the rim to be a copper-rich oxide. **Plate K** – BE image and copper line scan illustrating the reduction in copper from the interior (left) to the exterior (right) of Sample #3

UNIVERSITY - INDUSTRY COOPERATION AND INSTRUCTION IN MATERIALS SCIENCE AND ENGINEERING: GOOD INTENTIONS AND REALITY

Witold Brostow

Victor M. Castano

and

Pablo E. Montemartini

University of North Texas
Materials Science Department
P. O. Box 305310
Denton, Texas 76203-5310

Telephone: 940-565-4358
e-mail brostow@marta.phys.unt.edu
castano@marta.phys.unt.edu
pem0005@unt.edu

University - Industry Cooperation and Instruction in Materials Science and Engineering:

Good intentions and reality

Witold Brostow, Victor M. Castaño and Pablo E. Montemartini [1]

Department of Materials Science, University of North Texas, Denton, TX 76203-5310, USA;
pem0005@unt.edu

1. Introduction

The link with the productive sector has been a continuing concern of people entrusted with defining general policies of universities and colleges. Many universities have special offices, which provide the link. However, there is a paradox here: successful links are rare. In spite of the effort expended, there is much less success that one would expect.

Institutions of higher education would like to participate, in a direct and effective way, in the impressive social changes brought about by the available XXI century technologies. In this paper we consider the basic features of the problem: how should we provide instruction in Materials Science and Engineering (MSE). Needless to say, the objective is to provide college graduates able to perform well in the society, have social mobility, and able to sustain personal growth. In Section 2, 3, and 4 we shall consider these three aspects in some detail.

---

[1] presenting author

2. Training to work

We begin with the standard premise: colleges prepare students with the characteristics the companies require. Do the companies know what will happen in the future? Do they extrapolate into the future?

Of course, a modern university must qualify students for work, but work in conditions and in jobs that they will face during the next 50 years: great competition, innovations, managerial attitude and generation of own resources. The new professionals have to be able to solve real national problems in the technical, social and economic environment of the XXI Century World and to produce wealth.

3.The social mobility

The social mobility represents one of the more important promises of the universities in all countries, especially developing ones. Therefore, we should offer a model of a university that guarantees the social mobility. The model should be based on flexible and interdisciplinary curricula, capabilities for student exchange (nationally and internationally – as it is already practice in Europe) and the development of the managerial attitude. A direct relationship with the - already existent or potentials - wealth generating sources is pertinent also.

4. Personal growth.

Our students should adquire from the university clear positive examples of those cases in which "the urgent does leave time for the important". Unfortunately, the discussion about the current educational policies is mainly based on technical training. Human values are hardly contemplated in the curriculum design stage and even less in actual instruction.

We have here not only a moral or ethical problem, but also a practical one. We are forming young people for whom the values of solidarity, companionship, decency, modesty and integrity deserve the same - not less - attention that a world trade course, re-engineering or

ISO-9000. There has to be a reflection on the social consequences of an individual act. Moreover, our universities provide graduates with access to the consumption, but not necessarily with the social codes needed to understand the consequences that their behavior has for other individuals and for the environment. Practicing MSE has in fact strong consequences for the environment.

5. Teachers

One of the most recurrent concerns in the field of education is training and updating of instructors. Since one cannot provide what one does not have, it is clear that the efforts of modernizing the education should start with faculty training and updating. In MSE instruction we need to combine the current status of technology (which change continuously) with a vision of the future. For instance, how shall we use smart materials in the year 2025? Some specifics on this issue will be provided in the talk.

We know what needs to get done; in this respect the present paper reiterates ideas already known. The point of gravity is in procedures (including details) which will enable the implementation of our well-intentioned ideas.

MASS TRANSFER SENSORS AND MEMS DEVICES TO MEASURE SHEAR

Vijay Modi

Department of Mechanical Engineering
Columbia University in the City of New York
3000 Broadway
New York, New York 10027

Telephone: 212-854-2956
e-mail modi@columbia.edu

Vijay Modi

Mass Transfer Sensors and MEMS Devices to Measure Shear

Vijay Modi

Department of Mechanical Engineering
Columbia University

Key Words
Microelectromechanical Systems, Solid State Devices, Materials, Fluid Dynamics, Shear

Prerequisite Knowledge
Basics of physics, chemistry and engineering mathematics

Objectives
The measurement of shear is of great interest to fluid dynamics research, cellular biology, aerospace, marine, environmental and biomedical engineering since shear is the primary means of interaction between a flow and the solid surface. Several critical areas of technology rely on an accurate knowledge of local shear such as heat transfer in turbine blades, electrochemical etching/deposition of copper, metallization using wet- processes in advanced electronics and microfabrication of high-density patterned structures, colloidal transport in environmental engineering and validation of computational fluid dynamics simulations.

A discussion of the need for such measurements is provided along with a brief review of existing techniques for measurements. An electrochemical mass transfer based technique that permits shear measurement in liquids over a five order of magnitude range of shear with a 100 micron spatial resolution is described. The future challenge lies in developing techniques/devices to measure shear in gases at length scales that are of the order of 1 to 100 microns and time scales on the order of microseconds. In this regard the development of a novel MEMS device is described.

Equipment and Materials
Hot-wire anemometry, Electrochemical Mass Transfer Probe, Microfabrication Techniques

Introduction

The measurement of shear is of great interest since shear is the primary means of interaction between a flow and the solid surface. Shear is the genesis of drag and it is frequently an important factor in determining the rates of processes such as removal/ deposition of particles, transport of heat and chemical species at a wall. Several critical areas of technology rely on an accurate knowledge of local shear such as heat transfer in turbine blades, electrochemical etching/deposition of copper, metallization using wet- processes in advanced electronics and microfabrication of high-density patterned structures, colloidal transport in environmental engineering and validation of computational fluid dynamics simulations. Measurement of low

levels of shear is also of importance to the field of biomedical engineering. Shear stress on endothilial cells in macrovascular beds is related to injury to cells. The ability to measure the associated low levels of shear would provide a means to quantify their relationship to injury and disease. In most applications noted above the shear levels typically range from 0.1 to 40 Pa.

The relevance of shear to heat and mass transfer applications is well understood. Lofdahl and Gad-el-Hak [1,2], recently reviewed shear sensors, pressure sensors and their importance to turbulent flow control. Some of the novel future applications of shear sensors are however likely to come from biological and biomedical applications. In most prior biomedical research applications the wall shear is deduced from the measurement of bulk velocity or flow rates. Since the flows are generally laminar, an estimate or measurement of the size and assumed shape of vessel suffices to determine shear. Some such studies are: the work by Moore and Glagov (3) (an attempt to understand the relationships of flow field properties to the localization of plaque relating to atherosclerosis in humans), Wechezak and Viggers (4) (effects of fluid-generated shear stress on cells undergoing mitosis and cytokinesis), Irace and Carallo (5) (mechanisms underlying macrovascular complications), Takahashi and Okuda (8) (role of shear in mediated gene expression) and Jacobs et al (10) (bone mechano-transduction). Such studies indicate the need for a direct measurement of shear.

Indirect Measurement

Traditional techniques such as a Stanton gauge, Preston tube or a sublayer fence are indirect measurements of shear and rely on pressure measurement. [11-14] They rely on accurate machining, calibration and small pressure differential measurement. For a good review, see Goldstein [15].

Another indirect technique relies on heating small thermal elements near or flush with the wall. The element is maintained at a constant temperature and the heating current is related to the local wall shear stress (16). Fage and Falkner (17) were the first to study the relationship between local wall shear and the rate of heat transfer from small thermal elements. Tillman (18) used this technique to establish the law of the wall for turbulent boundary layers. Some designs are flush mounted (16), or with wire protrusions of only 1 micron into the flow, so there is minimum interference with the flow. They are also fast reacting and small enough to measure turbulent flows. Elements as small as 12.7 μm were developed(17) with a frequency response upward of 300 kHz (19). The repeatability of calibration and frequency response of the sensors is limited by the inability to completely insulate the sensor from everything but the flow. This is particularly difficult for the flush mounted sensors which otherwise have the advantage of not interfering with the flow. The relationship between the heat transfer and the shear itself changes with the nature of the flow and is difficult to establish analytically in turbulent flows which are not boundary layer type flows, e.g. impinging flows.

We have recently used hot-wire anemometry to carry out velocity measurements within the viscous sublayer for the purpose of determining the local wall shear on an impingement plate. These measurements represent the first direct measurement of shear in turbulent impinging slot jets. The distance from the wall to the edge of the viscous sublayer varies with Reynolds number. With a specially designed boundary layer probe from TSI, we will be able to make mean and turbulence intensity measurements at y^+ as small as 2.5 along the wall in all regions except perhaps the region immediately below the jet. There are three features of this technique that permit accurate measurement of shear. First, the calibration of the hot-wire is carried out in the

same near wall position as that used in the measurement using a flat-plate boundary layer with a known Blasius solution. This permits one to account for the effects of the wall on the hot-wire calibration without any assumed correlation. Moreover this has the advantage of permitting calibration of the wire for much lower velocities than otherwise possible with the use of a micro-manometer. Second, a non-contact optical method is used to determine the wire distance from the wall. Third, mechanical design of the probe assembly ensures that the distance between hot-wire and the wall remains the same during the measurement of the distance, calibration of the probe and the actual measurement of the velocity.

Electrochemical Mass Transfer Probe

Another technique that our group (A.West, D. Yang, B. DeBecker, M. Chen and V. Modi) has used relies on an electrochemical technique described by Hanratty in the volume edited by Goldstein (15). In our studies a mass transfer sensor consisting of a 0.1 mm×20.3 mm ($=L\times W_s$) platinum foil, cast in a cylindrical mold is used. The sensor design equation provides a relationship between the Nusselt number *Nu* and the wall shear stress given in terms of a skin friction coefficient, C_f (evaluated at the sensor's midpoint, i.e. x_M). The relationship can be shown to be:

$$\mathrm{Nu} = 1.01\alpha \mathrm{Sc}^{1/3} C_f^{1/3} \mathrm{Re}^{2/3}$$

$$\text{where } \alpha = \left[\frac{(1+f)^{3/2} - (1-f)^{3/2}}{f}\right]^{2/3} \quad \textit{where } f = \frac{\gamma_M L}{2\beta_M}.$$

Some of the advantages of this approach are that the probes are flush mounted, so this technique does not disturb the flow. The frequency response is largely limited by the measuring equipment and the size of the sensor. For the present sensor it was possible to acquire data in a 1 to 10 kHz range. The probe can also be used to examine turbulent flows without making any special assumptions about the behavior of the turbulent Prandtl or Schmidt numbers as long as the sensor is sufficiently small. There are no substrate losses, as with thermal techniques and hence the system can be calibrated analytically. A particular limitation is however the need to carry out the experiments in a liquid system with a specified chemistry. The flow cells must be constructed out non-metallic or stainless steel materials. Hence most applications of this approach are for model laboratory experiments. In the following section the use of microfabrication techniques for making small but rugged probes is discussed.

MEMS Based Sensors

MEMS devices can also becomes tools for research into the understanding of fluid flow and heat/mass transport since they provide the ability to sense and measure at physical scales that are becoming smaller. Their small physical scales may also allow the combination of sensing, actuation and control of flow for systems of much larger scale with applications in the automotive, aerospace, structural, manufacturing, and process industries.

Indirect measurement

One example of such a device is a micro thermal shear-stress sensor. This is a MEMS built heated flush-mounted thin-film that uses the thermal method of determining shear. A

drawback of using thin films in thermal shear measurement sensors is that smaller the size the greater the fractional losses to the substrate, thus reduced sensitivity. The designers of this micro sensor (20) reduced this problem by using MEMS to creating a thin vacuum cavity under the sensor, which insulated the thin film sensor from the substrate. With this technique they were able to design a sensor of dimensions 80-200 μm, with a frequency response of 70 kHz.

Direct Measurement

Padmanabhan et al(21) used MEMS fabrication techniques to suspend a 125 μm square by 7 μm thick silicon element by four 300 μm long thin tethers. The square element partially shaded two photodiodes from a laser that shined down onto the element. As the shear force from fluid flow moves the element, one of the photodiodes would be further shaded, and the other uncovered. The difference in electric current from the diodes was translated into shear force. This is first successful example of a direct measurement of force for evaluating shear at a sub millimeter physical scale. Packaging of this design into a self-contained probe poses a difficulty because of the need for an external laser light source.

The goal of our present effort is to develop a MEMS-based shear stress sensor that will be from 10 to 100 microns across. Hence the external size of our packaged sensor will be of the same order of magnitude as a current MEMS-based pressure sensor. These devices are typically cylindrical in shape, and have a packaged size of roughly 1 mm diameter by 5 mm long. We are currently developing a sensor that consists of a cantilevered beam, with a larger flat surface at the end of the beam exposed to the shear force. This shear force can be order of 0.1 to 1 nanoNewtons leading to deflections of the fiber tip on the order of several nanometers. The measurement of a differential electrostatic force applied to the beam to contact pads at either end of the sensor surface provides a means to establish the shear force. A schematic of the design is shown in the figure.

References:

(1) Lofdahl L. and Gad-el-Hak M., MEMS-based pressure sensors and shear stress sensors for turbulent flow, *Meas. Sci. and Tech.*, 10, 665-686, 1999.

(2) Lofdahl L. and Gad-el-Hak M., MEMS applications in turbulence and flow control, *Prog. Aero Sci*, 35, 101-203, 1999.

(3) Moore, JE., Xu CP., Glagov, VS., Zarins, CK., Ku, DN, Fluid wall shear-stress measurements in a model of the human abdominal aorta , *Atherosclerosis* 110, 225-240, 1994.

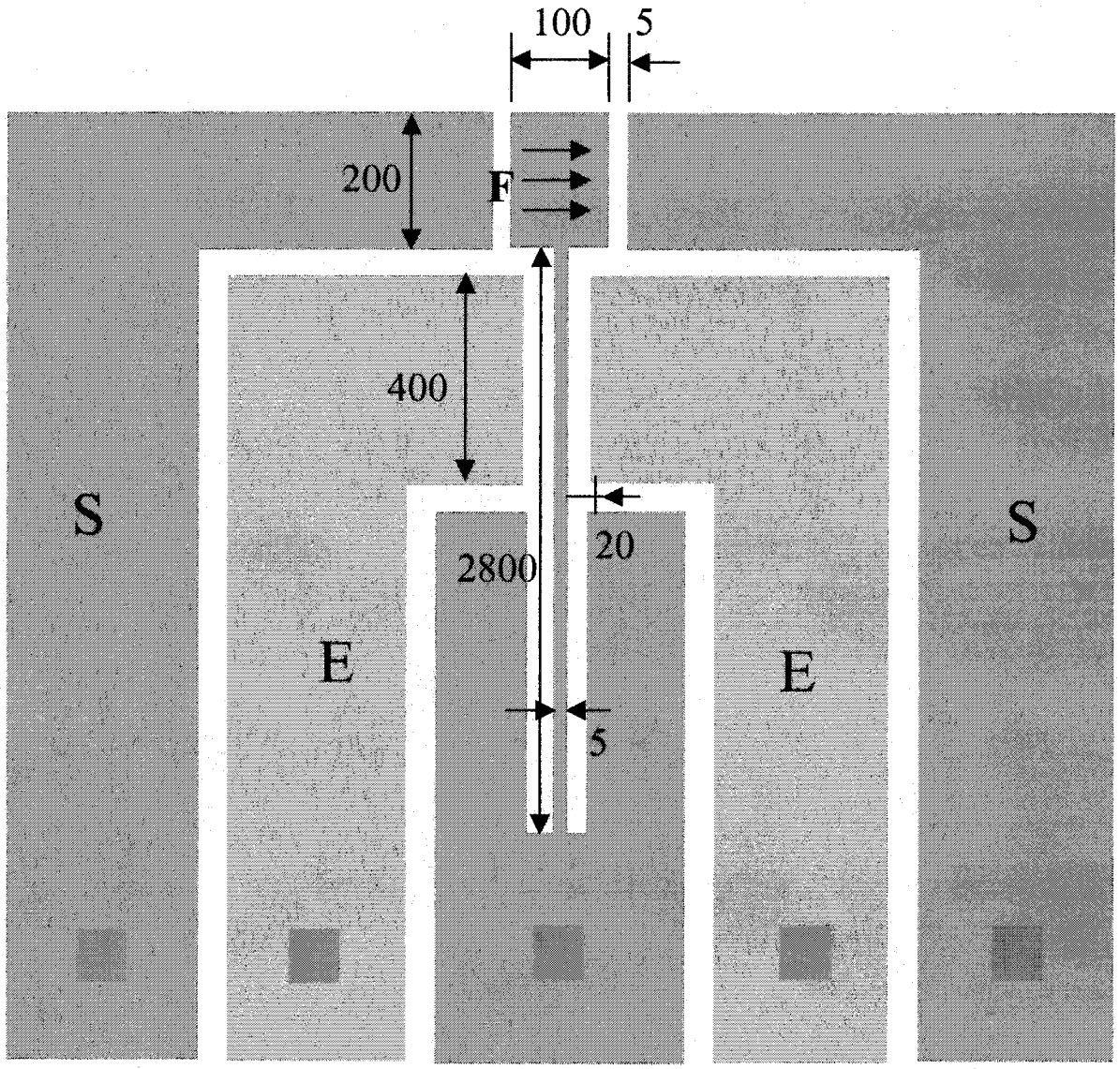
(4) Wecgezak, AR, Viggers, RF, Coan, DE, Sauvage, LR, Mitosis and cytokinesis in subconfluent endothelial cells exposed to increasing levels of shear-stress, *J. Cellular Physiology*, 159, 83-91, 1994.

(5) Irace C, Carallo C, Crescenzo A, Motti C, De Franceschi MS, Mattioli PL, Gnasso A NIDDM is associated with lower wall shear stress of the common carotid artery, *Diabetes*, 48, 193-197, 1999.

(6) Oyre S, Paaske WP, Ringgaard S, Kozerke S, Erlandsen M, Boesiger P, Pedersen EM, Automatic accurate non-invasive quantitation of blood flow, cross-sectional vessel area, and wall shear stress by modeling of magnetic resonance velocity data, *European J. Vascular and Endovascular Surgery*, 16, 517-524, 1998.

(7) Khder Y, Briancon S, Petermann R, Quilliot D, Stoltz JF, Drouin P, Zannad F Shear stress abnormalities contribute to endothelial dysfunction in hypertension but not in type II diabetes, *J. Hypertension*, 16, 1619-1625, 1998.

(8) Yan C, Takahashi M, Okuda M, Lee JD, Berk BC, Fluid shear stress stimulates big mitogen-activated protein kinase 1 (BMK1) activity in endothelial cells - Dependence on tyrosine kinases and intracellular calcium, *J. Biological Chemistry*, 274, 143-150, 1999.
(9) Sirois E, Charara J, Ruel J, Dussault JC, Gagnon P, Doillon CJ, Endothelial cells exposed to erythrocytes under shear stress: An in vitro study, *Biomaterials*, 19, 1925-1934, 1998.
(10) Jacobs CR, Yellowley CE, Davis BR, Zhou Z, Cimbala JM, Donahue HJ, Differential effect of steady versus oscillating flow on bone cells, *J. Biomechanics*, 31, 969-976, 1998.
(11) Stanton, T.E., Marshall, D., Bryant, C.W., On the Condition at the Boundary of a Fluid in Turbulent Motion, *Proc. Royal Society*, London Ser. A, 97, 413-434, 1920.
(12) Hool, J.H., Measurement of Skin Friction Using Surface Tubes, *Aircr. Eng.*, 28, 52, 1956.
(13) East, L.F., Measurement of Skin Friction at Low Subsonic Speeds by the Razor-Blade Technique. *Aero. Res. Counc. London,* R&M, 3148, 1959.
(14) Bradshaw, B.A, Gregory, M.A., The Determination of Local Turbulent Skin Friction from Observation in the Viscous Sub-Layer, *Aero. Res. Coun. London*, R&M, 3202, 1961.
(15) Goldstein, R.J., Fluid Mechanics Measurements, Hemisphere Publishing Corporation, NY, NY. 1983.
(16) Liepmann, H. W. , Skinner, G. T., Shearing-Stress Measurements By Use of a Heated Element. NACA TN 3269, 1954.
(17) Fage, A., Falkner, V.M. On the Relation between Heat Transfer and Surface Friction for Laminar Flow *Aero. Res. Counc. London,* R&M No. 1408, 1931.
(18) Ludwieg, H., Tillman, W., Investigation of the Wall Shearing Stress in Turbulent Boundary Layers, NACA TN 1285, 1950.
(19) TSI Corporation Web site, www.tsi.com. 1998.
(20) Huang, J., Liu, C., Jiang, F., Tung, S., Tai, Y., Ho, C., Fluidic Shear-Stress Measurements Using Surface-Micromachined Sensors. *Proc. IEEE Region 10 Conf. Microelectronics and VLSI, Hong Kong*, 12-15, 1995.
(21) Padmanabhan, A., Goldberg, H.D., Breuer, K.S., Schmidt, M.A., A Silicone Micromachined Floating-Element Shear-Stress Sensor with Optical Position Sensing By Photodiodes, *8th Int. Conf. On Solid State Sensors and Actuators,* Stockholm, Sweden, Jun 25-29, 436-439, 1995.

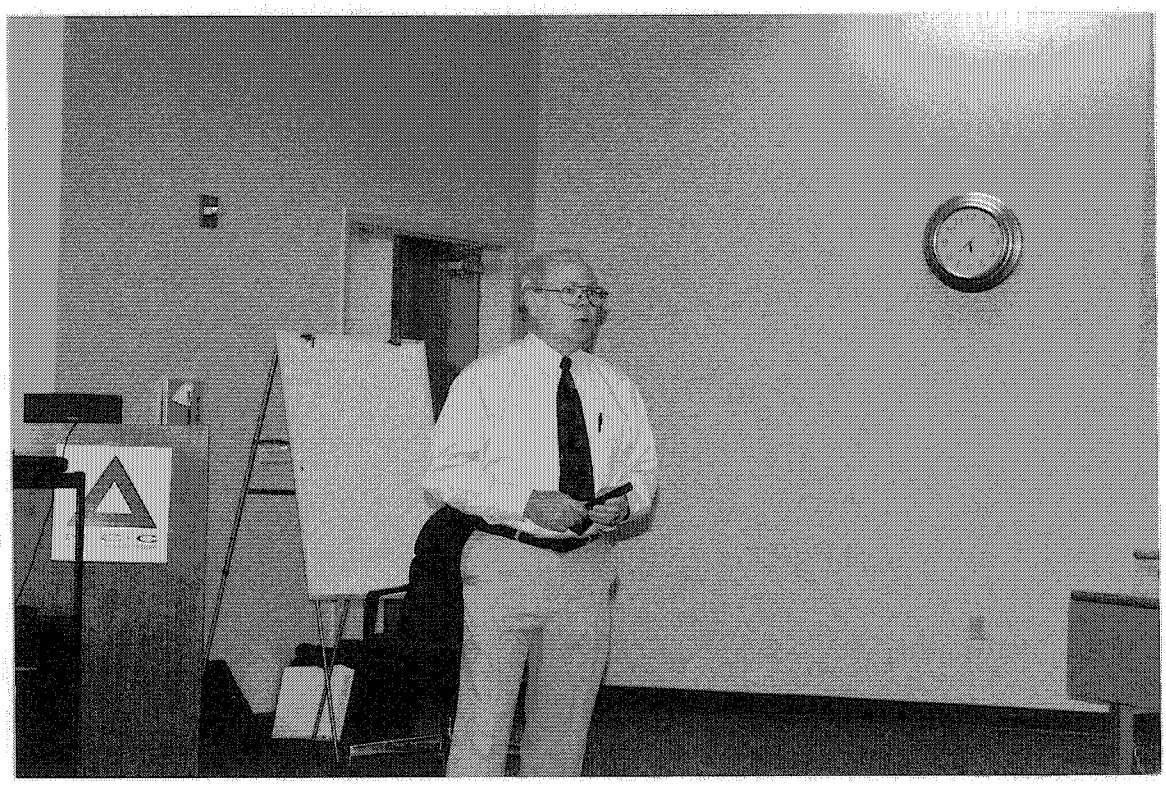

100
5
200
F
400
S
S
20
2800
E
E
5

THE MAGSET PROJECT
MATERIALS AS THE GATEWAY (AND GLUE) FOR SCIENCE, ENGINEERING AND TECHNOLOGY

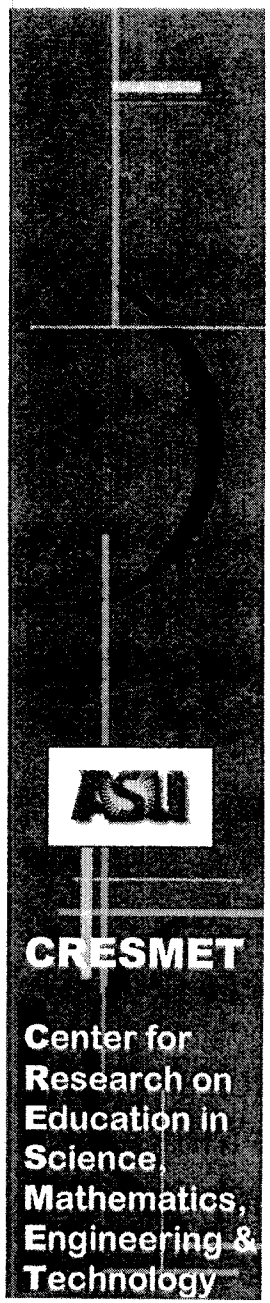
Don L. Evans

Director, Center for Research on Education
in Science, Math, Engineering, and Technology
Arizona State University
Tempe, Arizona 85287-5006

Telephone: 480-965-5350
e-mail devans@asu.edu



Don L. Evans



The MAGSET Project

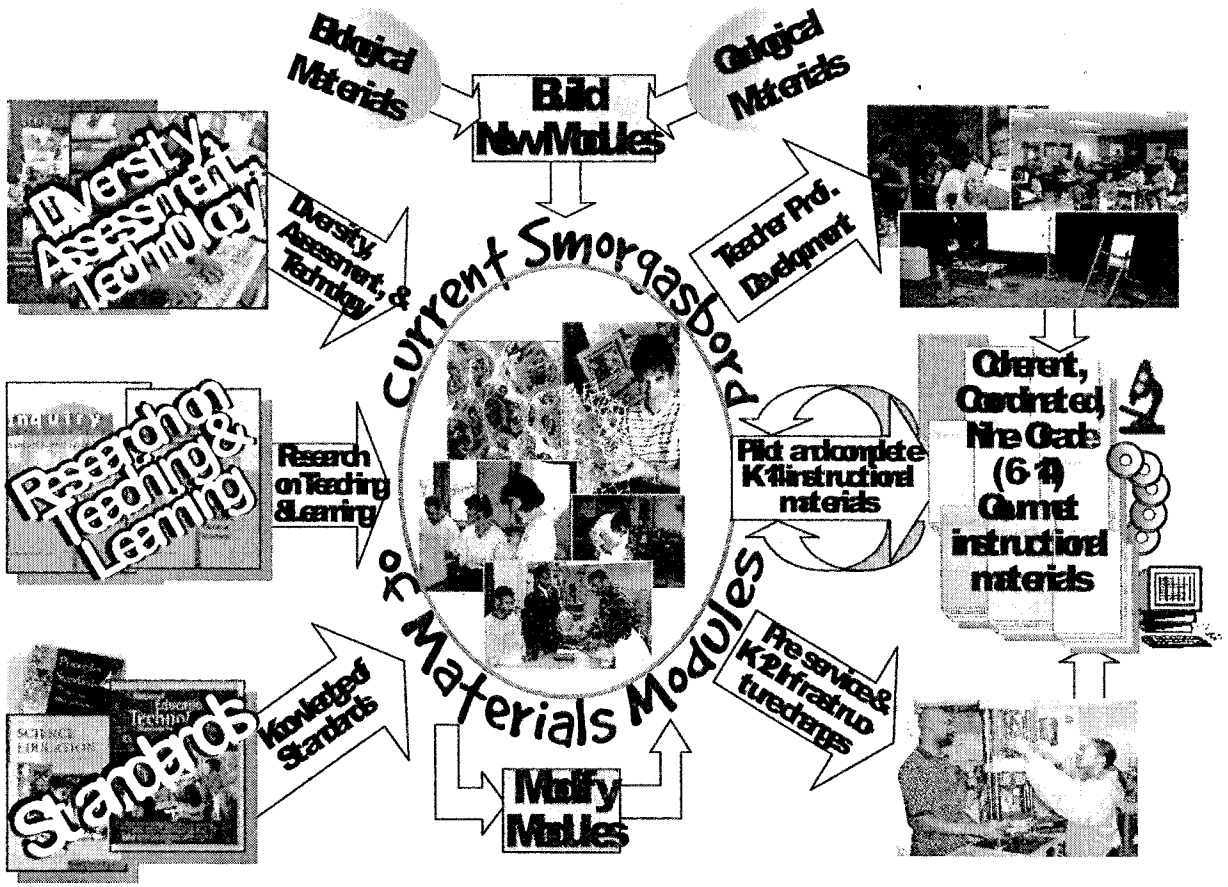
Materials As the Gateway (and Glue) for Science, Engineering and Technology

- MAGSET is a long-range effort to significantly change science literacy education in U.S. K-14 system;
- The AY 2000-2001 will be a vision-setting, planning, and infrastructure development time;
- A MAGSET steering/oversight committee will guide design and development of coherent science education curricula;
- MAGSET will use three National Design and Coordination Teams to:
  - Set a common vision for the products and processes to be developed;
  - Develop the "backbone" of articulated, coherent curricula;
  - Pick from a smorgasbord of modules and activities to create "healthy, gourmet curriculum feasts."

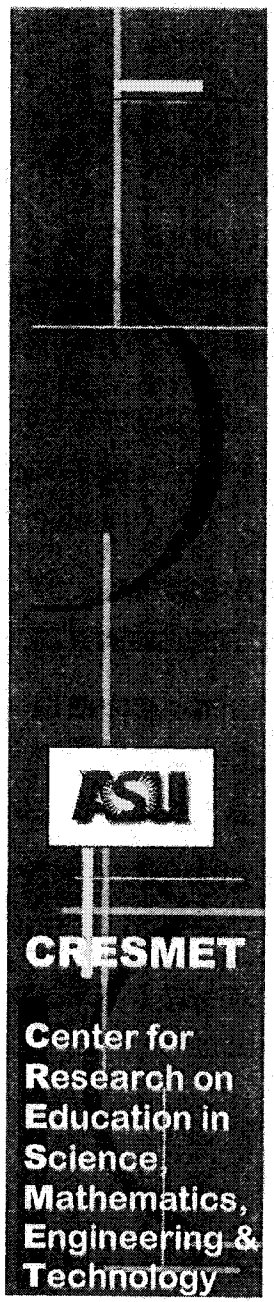
NORTHWESTERN UNIVERSITY
ASU Arizona State University | Norfolk State University | University of Washington
PENNSTATE | The University of Texas at El Paso | The University of Iowa

MAGSET: A Start-Up Effort to Improve Science Literacy in K-14 Education

MAGSET Project Overview



MAGSET: Materials As the Gateway (and Glue) for Science, Engineering and Technology



MAGSET Goals

Utilize materials as the gateway and the glue in which K-14 SMET learning can most effectively be linked for the general population by:

- Cultivating creative and critical thinking for life-long learning through personal experience in, and understanding of, a world shaped by science and technology;
- Achieving scientific and technological understanding as a necessity for workplace empowerment and citizenship in a free society;
- Championing, modeling, and executing a new approach for teaching and learning of SMET for all students that expressly values the cultural orientations of women and minority populations;
- Transforming teacher education programs and the infrastructure of education to insure success;
- Establishing exemplary curricula and supporting tools that will be used nationally in K-14 programs;
- Establishing a new model of SMET education by using rich, hands-on, minds-on, tangible experiences.

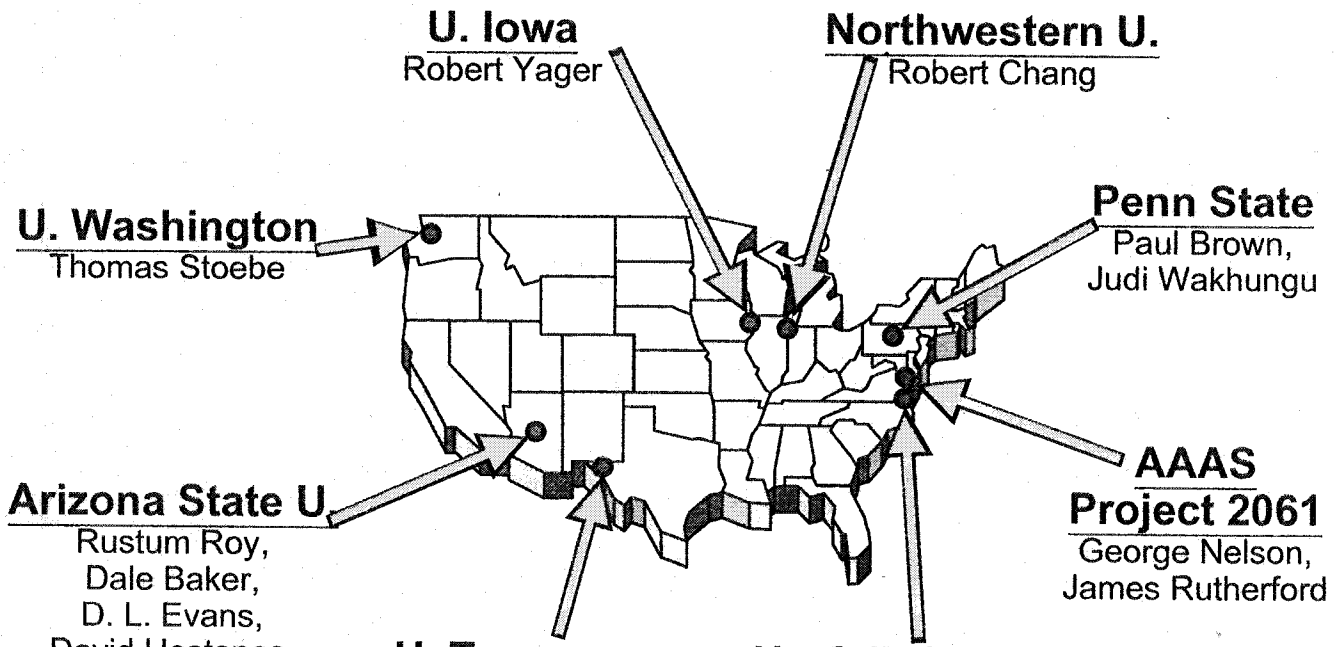
ASU Arizona State University · Northwestern University · Norfolk State University · University of Washington · Penn State · The University of Texas at El Paso · The University of Iowa

CRESMET

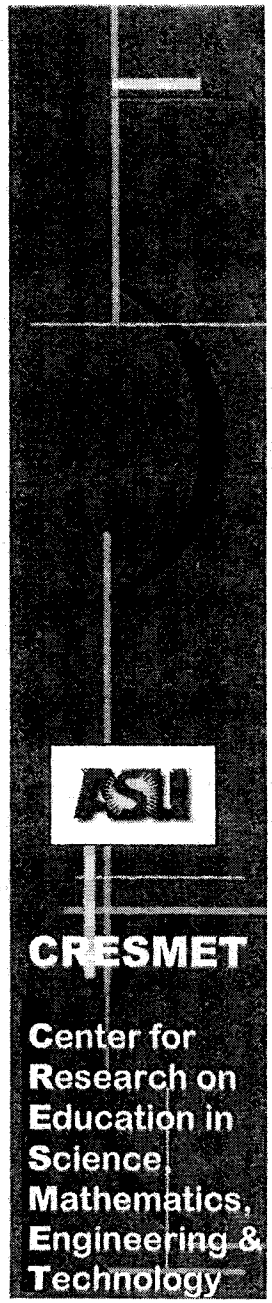
Center for Research on Education in Science, Mathematics, Engineering & Technology

MAGSET: Local Points of Presence connected within a National Partnership

Participating Institutions and Steering Committee Members



NORTHWESTERN UNIVERSITY
ASU Arizona State University
Norfolk State University
University of Washington
PENNSTATE
The University of Texas at El Paso
The University of Iowa

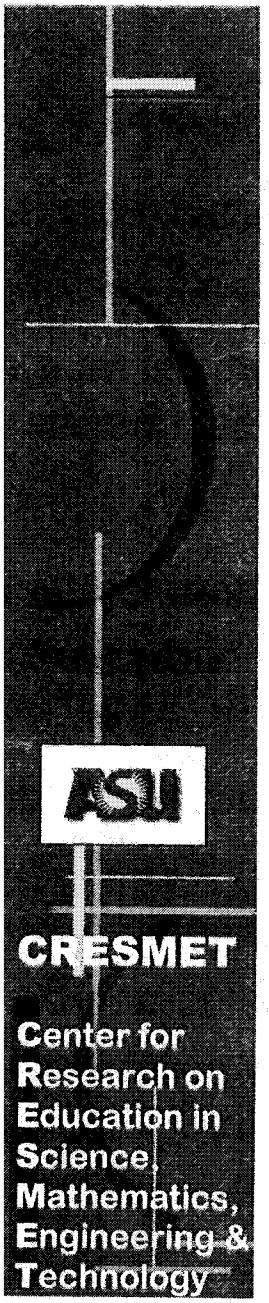


MAGSET Special Target Groups

MAGSET will focus SMET education for:

- All K-14 students, especially,
  - ♦ Non-science/engineering (NSE) track students,
  - ♦ Under-represented populations.
- Pre-service and in-service K-12 teachers,
- SMET faculty and instructors in Community College, 4-year College, and University general education programs,
- Supporting infrastructure people

NORTHWESTERN UNIVERSITY
ASU ARIZONA STATE UNIVERSITY NORFOLK STATE UNIVERSITY UNIVERSITY OF WASHINGTON
PENNSTATE The University of Texas at El Paso THE UNIVERSITY OF IOWA

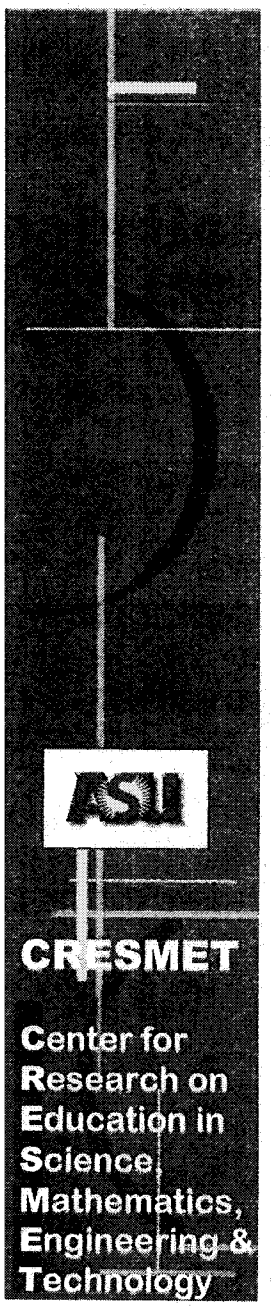


MAGSET is K-14 Science Literacy Reform Using Materials Science/Engineering Theme

The US needs a sweeping K-14 SMET education reform as a priority in national science policy. Some of the problems are:

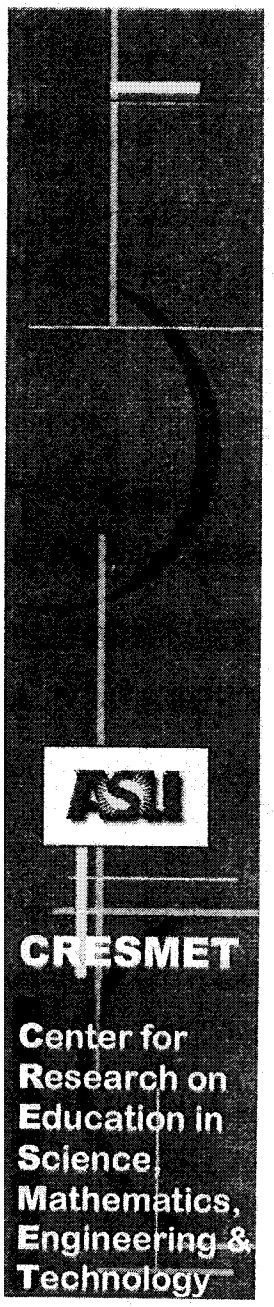
- Few curricula exist that address "relevance to the learner" and the problem of "over-stuffed" science instruction;
- Most curricula do not address the needs of under-represented and under-served students;
- There is a lack of interdisciplinary, structured, coherent, and articulated curricula;
- Addressing all science standards with existing curricula is problematic.

NORTHWESTERN UNIVERSITY
ASU ARIZONA STATE UNIVERSITY NORFOLK STATE UNIVERSITY UNIVERSITY OF WASHINGTON
PENNSTATE The University of Texas at El Paso THE UNIVERSITY OF IOWA



Why Materials Science/Engineering Emphasis?

- All citizens/students deal with materials every day (see, touch, and use);
- Chemistry, physics, biology are all linked to materials;
- Materials cover the range from highest tech semiconductors and superconductors, to bone repair, to concrete and fly ash;
- Strong ties can be established to biological materials and geological materials to meet a range of K-12 science standards.

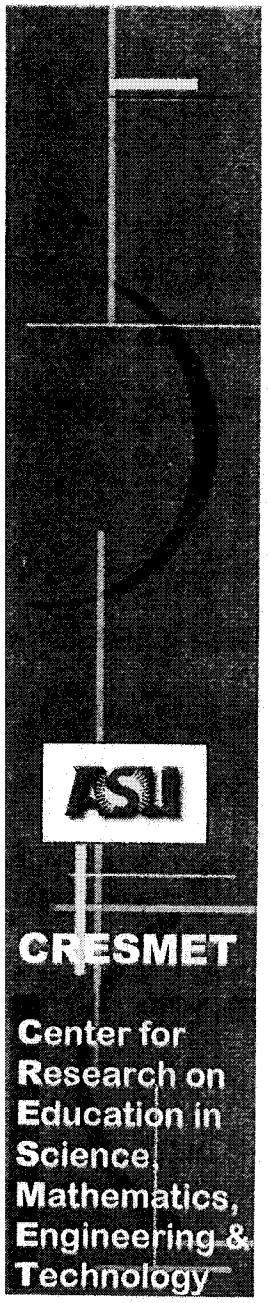


Want to Contribute/Participate?

We are looking for enthusiastic help and/or good materials-related, K-14 modules and activities in the physical sciences, life sciences, earth and space sciences:

- To place your project/activity in the MAGSET database, fill out the interactive form found linked to:
  www.eas.asu.edu/~magset
- National Design and Coordination Teams are being formed this year. To tell us of your interests and to get on our distribution list, send an email to
  magset@asu.edu
- A national, open meeting on this approach to science education is being held at the *National Academy of Engineering* on March 1, 2001. If you are on our distribution list, you will be notified of the details.

NORTHWESTERN UNIVERSITY
ASU ARIZONA STATE UNIVERSITY NORFOLK STATE UNIVERSITY UNIVERSITY OF WASHINGTON
PENNSTATE The University of Texas at El Paso THE UNIVERSITY OF IOWA



MAGSET Uniqueness

- Established national network of school/university partnerships serve as points of presence for local reform;
- Participants are close to the problems:
  - ♦ Effective partnerships;
  - ♦ Insures adaptability.
- Uses National Design and Coordination Teams:
  - ♦ Teams are diverse collections of stakeholders;
  - ♦ Meet quarterly w/one day of overlap;
  - ♦ Yearly national meeting (co-sponsored by various professional societies).
- Conducts multiple, geographically distributed pilots that are aggregated nationally;
- Focus on a theme, not a discipline, is unique.

NORTHWESTERN UNIVERSITY
ASU ARIZONA STATE UNIVERSITY NORFOLK STATE UNIVERSITY UNIVERSITY OF WASHINGTON
PENNSTATE The University of Texas at El Paso THE UNIVERSITY OF IOWA

TECHNOSPHERE. AN ENVIRONMENTAL STUDIES SEMESTER FOR UNDERGRADUATE MATH, SCIENCE, ENGINEERING, AND TECHNOLOGY MAJORS

Leonard W. Fine

Department of Chemistry
Columbia University in the City of New York
Havemeyer Hall
New York, New York 10027

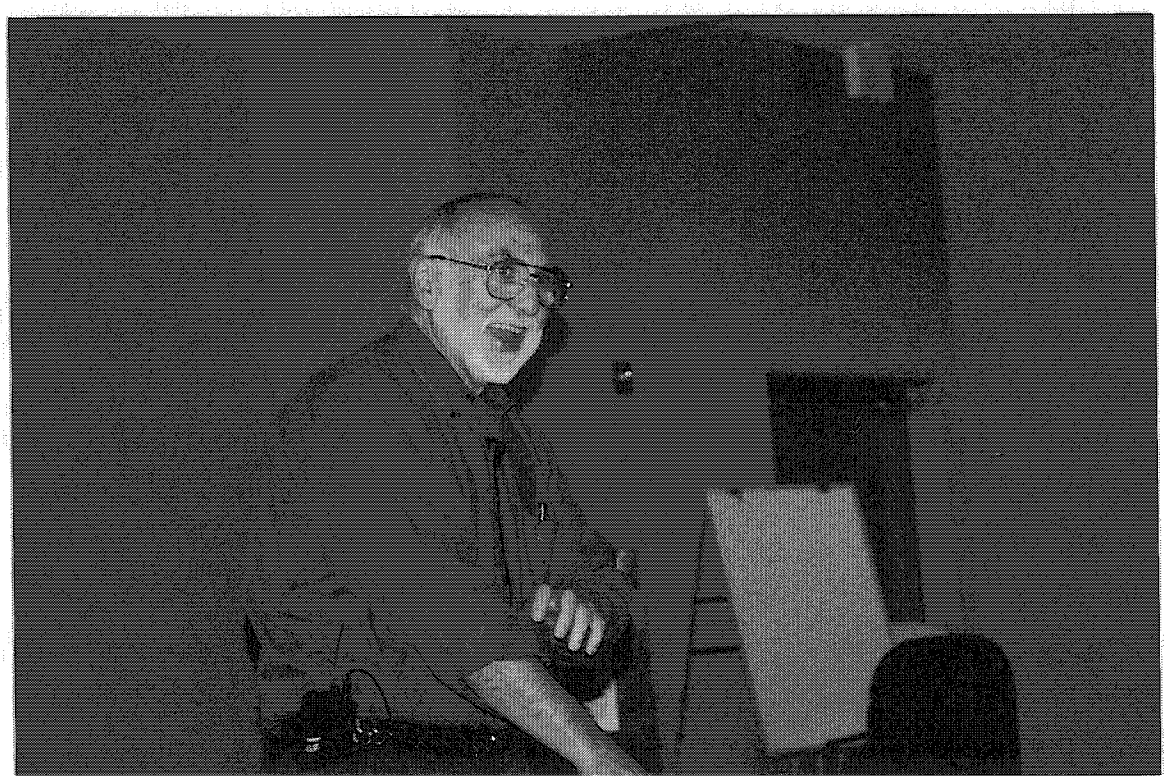
Telephone: 212-854-2017
e-mail fine@chem.columbia.edu

and

Morton Friedman

Columbia University
500 West 120th Street
Room 510 Mudd
New York, New York 10027

Telephone: 212-854-2986
e-mail Friedman@columbia.edu



Leonard W Fine

TECHNOSPHERE. An Environmental Studies Semester for Undergraduate Math, Science, Engineering, and Technology Majors.

Leonard Fine, Department of Chemistry and Morton Friedman, Department of Civil Engineering

Columbia University, New York, NY 10027.

Key Words

Education, Mathematics, Science, Engineering, Technology, Chemistry Environmental Studies

Prerequisite Knowledge

None

Objectives

This is a time of powerful forward momentum for engineering and applied science and for chemistry, physics and mathematics. Ours is an era marked by sophisticated, rapidly changing, all-pervasive technology, and by physical sciences and applied mathematics that universally transform the way we live and how we work. At the same time, we live in global environments that demand local attention. It has been said that these are the best of times and perhaps they are, but the pessimist fears that truth. Our greatest responsibility to successors is to make them more aware of the context of their actions. TECHNOSPHERE semester is an integrative, seven-course curriculum of interdisciplinary education presented at Columbia University's Biosphere 2 campus to take advantage of the unique research and education opportunities on the campus and in the Biosphere 2 facility. This semester curriculum has been developed to take advantage of growing awareness of planetary issues. The program emphasizes engineering and science field studies while stressing integrative research, technology development, and applied science. The curriculum allows students to meet standard second-year engineering and science requirements as they gain hands-on experience in real world applications of course content. Courses are structured to focus on the junctures of engineering curriculum elements with energy and other planetary management challenges readily demonstrated by a variety of campus surroundings. The authors will describe the program in words and pictures and provide wisdom on which – schools and students - should consider participating, and how to do it.

Equipment and Materials

Six biomes – ocean, rainforest, swamp, savanna, desert and agricultural – under a 3.1 acre glass dome enclosure that permits careful control of light, heat, and atmosphere.

Technosphere Semester

This is a time of powerful forward momentum for engineering and applied science and for chemistry, physics and mathematics. Ours is an era marked by sophisticated, rapidly changing, all-pervasive technology, and by physical sciences and applied mathematics that universally transform the way we live and how we work. At the same time, we live in global environments that demand local attention. It has been said that these are the best of times and perhaps they are, but the pessimist fears that truth. Our greatest responsibility to successors is to make them more aware of the context of their actions. To that end, Columbia University is committed to helping resolve what we perceive as a defining issue for the 21st century – the environment. The western campus at Biosphere 2 provides engineering and science students with an opportunity to study the Biosphere, the real world of our experience, in context.

Technosphere Semester is an integrative, seven-course curriculum of interdisciplinary education for undergraduate engineering and science majors students presented at Columbia University's Biosphere 2 campus to take advantage of the unique research and education opportunities on the campus and in the Biosphere 2 facility. This semester curriculum has been developed to take advantage of growing awareness of planetary issues as an appropriate element of the Columbia core curriculum concept of a full cultural education foundation for every undergraduate student.

The program will emphasize engineering and science field studies, integrative research and science seminars that include a seminar taught jointly with Earth Semester, Universe Semester, and Technology Semester faculty and directed at how the Biosphere – planet earth - works. The curriculum will allow students to meet standard second-year engineering and science requirements as they gain hands-on experience in real world application of course content. Courses are structured to focus on the junctures of engineering curriculum elements with energy and other planetary management challenges readily demonstrated by a variety of campus surroundings.

The campus focuses students on Biosphere-related studies and provides a surrounding, expansive real world learning venue that demonstratively enriches the curriculum. The campus offers a semester abroad like immersive experience with significantly reduced distraction from curricular content. Students have immediate opportunity to apply the skills they are developing in the real world. In addition to its advantageous relative proximity to Sandia and Los Alamos National Laboratories, the campus presents a natural setting for study of cogeneration; environmental pollution challenges from mining and other industrial/ commercial activities; and hydrology and water supply and pollution issues.

Course summaries

Physics: Introduction to elements of the three-term physics sequence, modified to include relativity, waves, quantum theory and quantum mechanics, reflection and transmission, properties of nuclei, fourier series and integrals, normal modes, uncertainty and wave-particle duality, stressing with environmental applications. This course has an experiential research component to be introduced by the Universe Semester faculty. 3 credits.

Mathematics: Introduction to elements of ordinary differential equations with applications to Biosphere 2. Mathematical modeling is introduced as a predictive tool in understanding dynamic atmospheric, ocean and earth systems as they are impacted by human behavior. This is equivalent to the standard Ordinary Differential Equations (ODE) course for engineers and scientists. 3 credits.

Chemistry: Introduction to structure and dynamics of the planet at the macro and micro scale. Equilibrium dynamics of solids and fluids in earth and planetary environments. Contaminants, adsorbates and interfaces provide a new approach to the traditional principles of introductory chemistry. Materials science and chemical physics provide the basis for understanding relevant environmental applications. The laboratory component of the course is both field study-based and distance learning in conjunction with laboratory classes in New York. 3 credits.

Energy: Broad introduction to the science (30%), technology (40%), economics (20%) and policy (10%) of energy systems. Includes energy and power, units, energy density and power density. Review of thermodynamics, vapor and air-standard power cycles. Car/ truck/ aircraft engines, steam and gas turbine power plants. Combined cycle gas turbines, cogeneration or combined heat and power. Renewable sources of energy. Wind turbines, farms, and storage systems. Solar photovoltaics, storage systems, hydrogen, fuel cells, and carbon problems. Open to students with first year physics and mathematics completed. 3 credits.

Energy Conversion Systems Laboratory: This instrumentation intensive laboratory course will include experiments on instrumented micro gas turbines, photovoltaics, fuel cells and wind turbines; measurement of temperature, pressure, flow velocity, flow rates. Students will develop familiarity with sensor and actuator use using workstations designed for multimedia learning in a laboratory. The course will subsequently expose students to the more complex sensor network of Biosphere 2 and the control software, hot wire and hot film anemometry. Students will be introduced to use of oscilloscopes, elementary circuits and software for data acquisition. 3 credits.

Integrative Technology course on how the Biosphere works – The Mechanical Biosphere: Brings Technology students into nine lectures taught by the Earth Semester Faculty, with the remaining 18 lectures to be taught by Universe and Technosphere Faculty in chemistry, physics, mathematics, statistics, and engineering. This course is open to all Biosphere 2 undergraduates. 3 credits.

An alternative open to Technosphere Semester students is to take the Planetary Management Module as elective credit.

Math, Science, Engineering, and Technology Seminar: A two-hour weekly integrative seminar, drawing on the resources of the Earth, Universe, and Technology programs in a given semester, as well as from visiting scientists and engineers. It will include 4 to 6 field trips that feature power generation, cogeneration, hydrology and water issues, uranium production and nuclear waste disposal, chemical pollution, and other subjects. Field trips will include such sites as Hoover Dam, the Asacrco open pit mines, the Bisbee deep mine, the Grand Canyon, and the Department of Energy's (DOE) Sandia and Los Alamos National Laboratory facilities. 2 credits.

Independent Research: All students will be expected to work and study under Technosphere Semester faculty mentors, Biosphere 2 engineering and chemistry research faculty and staff, University of Arizona faculty and researchers, and other mentoring opportunities to be made available to them. Examples of individual projects include work in chemical and mechanical engineering with sensors, detectors and sniffers, building research equipment and sensing devices, long term laboratory development projects, instrumentation tracking projects to continue over several semesters, hydrological chemistry applications, studies of campus facilities and phenomena for their chemical and engineering facets, smart or green building design, or innovative transportation and energy concepts. Students must earn a minimum of 4 credits in independent research. 4 credits.

Supporting Research Programs in Chemistry

Effect of Environmental Conditions on Ecosystems – The glass-enclosed Biosphere 2 not only allows environmental conditions within it to be varied in a carefully controlled manner, but also results in an environment inherently different to that of the biosphere. By varying the atmospheric composition and environmental conditions inside Biosphere 2, and monitoring the effect of these variations on the enclosed eco-systems, detailed investigations on how ecosystems chemically respond to varying environmental conditions are possible. In addition, by comparing and contrasting systems within Biosphere 2 and the same systems in the biosphere, we can systematically investigate how chemical responses in systems adapt to different environmental conditions.

Chemistry of Biotic Interaction – The Biosphere 2 laboratory provides a unique opportunity for research in chemical communication and chemical defense mechanisms of species under relatively simplified ecological conditions. Conducting research of this

type in the Biosphere 2 allows for isolation, bioassays and characterization at the site of collection, under "natural" conditions, resulting in more meaningful results. At the same time the closed structure of Biosphere 2 also allows introduction of species into the enclosure in a controlled manner making possible studies on the socio-biological and chemical factors that determine the success or failure of species survival.

Chemical and Biological Studies of "Artificial Systems" – The Biosphere 2 laboratory provides numerous opportunities to investigate life under controlled conditions. The construction of an artificial ocean provides a particularly appealing opportunity to study how terrestrial life adapts to aqueous saline environment. Evaluating which organisms now thrive in the Biosphere 2 ocean will lead to significant knowledge of the short-term saline environment adaptation process. This information will provide significant insight into the overall process of adaptation and will, on the longer time scale, yield data on the rates of salinity-tolerance evolution.

Stable Isotope Studies of Nitrous Oxide Biogeochemistry – Despite being present in only trace amounts, in the atmosphere, nitrous oxide (N2O) exerts a disproportionately large influence on the terrestrial climate. Yet, the global budget of N2O is presently not well quantified. We are interested in undertaking isotopic studies of N2O, especially those that can be uniquely studied in the Biosphere 2 laboratory, such as the biological production of N2O, to improve our understanding of N2O biogeochemistry. A better understanding of N2O biogeochemistry would help produce models that better predict atmospheric responses to human activities.

Environmental Sensors – The research areas described above will require parameters like atmospheric composition, humidity, temperature, and light intensity to be carefully controlled, varied and monitored. Feedback systems that sense changes and respond to these changes will be required, as well as on-line and field-site analysis of air, soil and water. All of these measurements and controlling devices can take advantage of micro-electro-mechanical (MEMS) technology. This technology is the basis for devices that monitor pressure and temperature, detect low levels of hydrogen, hydrocarbons, and nitrogen oxides, and control operation of miniature robots, and micropumps. The group of researchers involved in this area will work closely with the researchers in the above four groups designing MEMS devices that can be used for their applications. Given the relevance of such devices for an economy and industry that is increasingly environmentally conscious, this group will include scientists and engineers from the industrial partners to ensure that the technology being developed is viable for industrial applications.

SUPPORTING RESEARCH PROGRAMS IN ENGINEERING

The emergence of MEMS (micro-electro-mechanical systems) and nanoscale sensors in the past 20 years has decreased dramatically the size, weight and cost of sensors and sensor arrays by orders of magnitude, while at the same time improving their spatial and temporal resolution and increasing accuracy. Thus, in systems that previously were limited to one or a few sensors, emerging technologies make it possible to conceive

of possibly thousands of sensors integrated into systems to improve their performance, increase their lifetime, make them more flexible in use, and decrease their life cycle costs. The integration of sensors with electronics has opened new modes of recording and transmitting data, particularly by wireless transmission. These open up new and exciting possibilities for the Biosphere 2 research laboratory and will be of interest to DOE in particular.

It has become possible to incorporate arrays of sensors into systems in ways that often expose them to hostile environments that include high temperatures, high vibration, high noise, or corrosive chemicals. In biological systems, sensors can be developed that themselves do not affect the system or organism. The interest in new sensing and imaging technologies and critical applications for these technologies is ubiquitous across all science and engineering disciplines. Hybrid electrical-mechanical-biological sensors are one of the most promising new frontiers of the microelectronics revolution. There are new and emerging sensor technologies that were virtually unknown five years ago and that can be applied to the solution of critical problems. To quote a Defense Advanced Research Projects Agency (DARPA) mission statement: "It is a revolutionary, enabling technology that can completely change the way people and machines interact with the physical world."

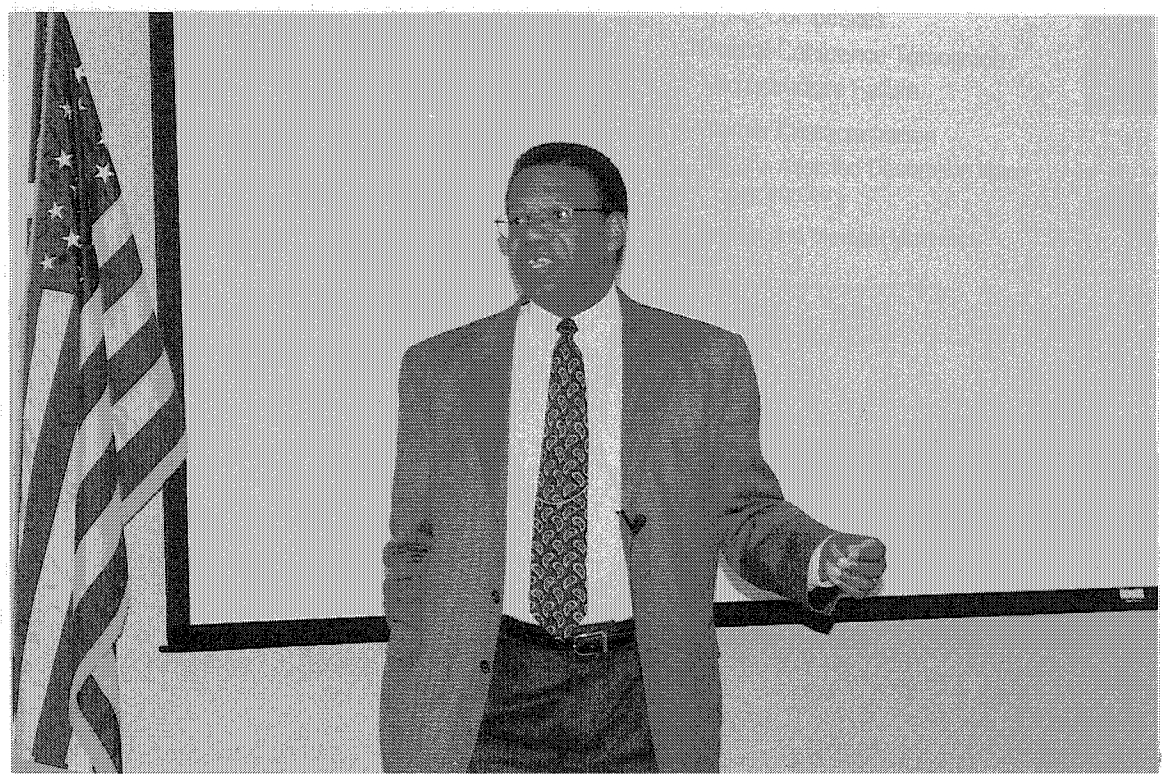
As we noted in the abstract, this is a time of powerful forward momentum for engineering and applied science and for chemistry, physics and mathematics. We believe we are stepping into the 21st century with an innovative and timely *collaborative* program that can set new standards for educating the next generation of scientists and engineers.

OVERVIEW OF MATERIALS SCIENCE AND ENGINEERING LABORATORY PREVIEW NEW:UPDATE 2001

Gale A. Holmes

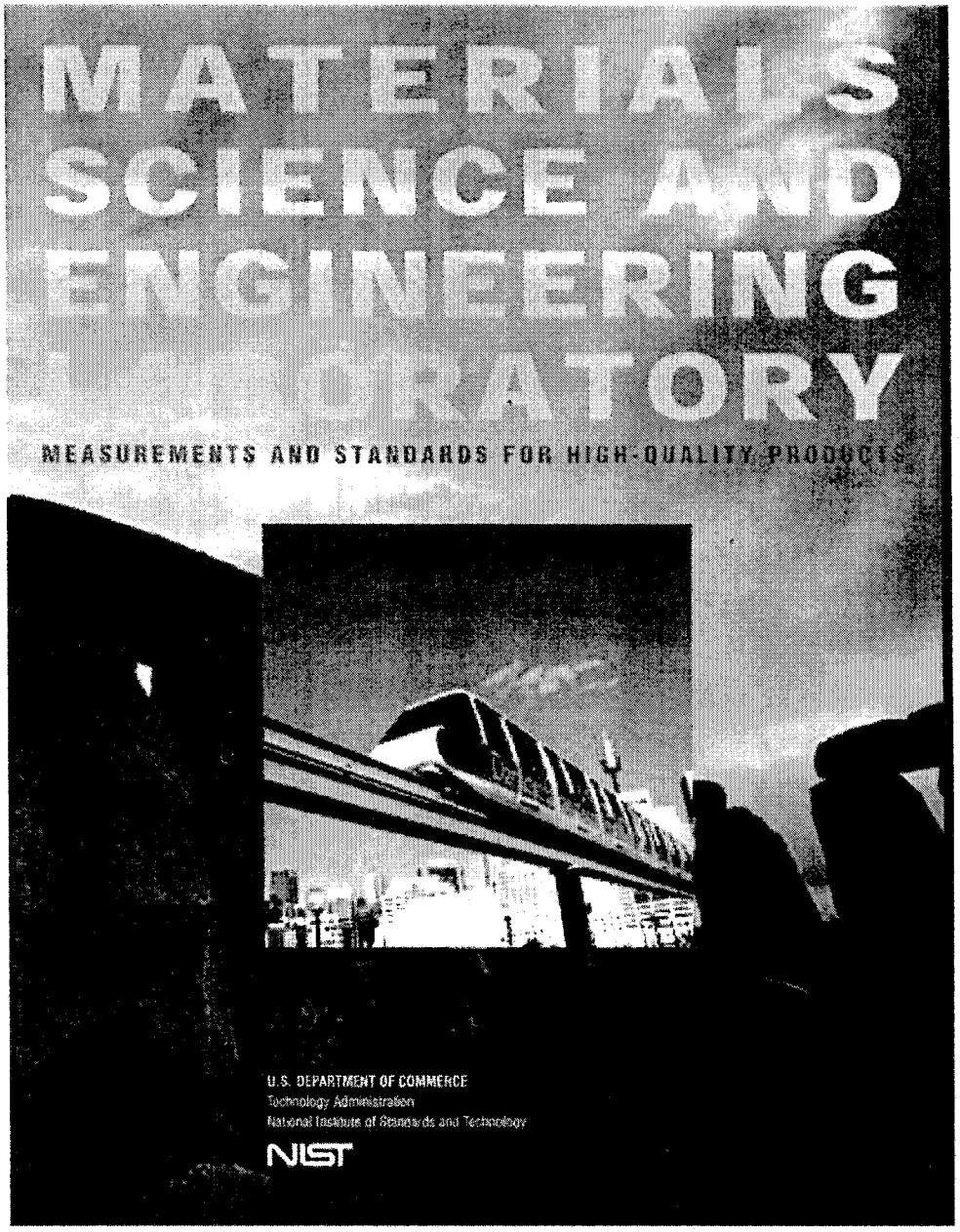
Polymers Division (854)
Polymers Building (224), Room B116
National Institute of Standards and Technology
100 Bureau Drive, Stop 8543
Gaithersburg, Maryland 20899-8543

Telephone: 301-975-5280
e-mail gale.holmes@nist.gov



Gale A. Holmes

Promote U.S. economic growth by working with industry to develop and use a measurements and standards infrastructure for materials



NIST National Institute of Standards and Technology

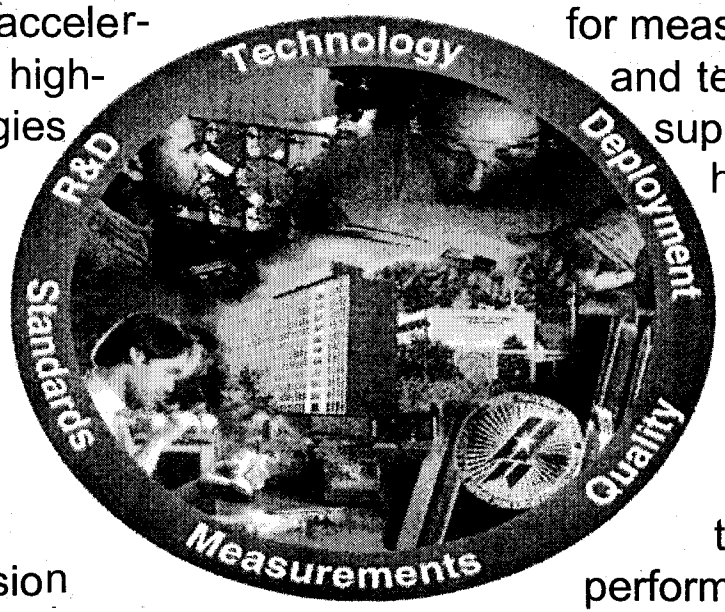
NIST Assets Include:

Advanced Technology Program

Unique co-funding partnership between NIST and private industry to accelerate the development of high-risk, enabling technologies with broad benefits for the entire economy and for society.

Manufacturing Extension Partnership

Nationwide network of locally managed extension centers offering technical assistance and best business practices to the Nation's 385,000 smaller manufacturers in all 50 states, DC, and Puerto Rico.



Measurements and Standards Laboratories

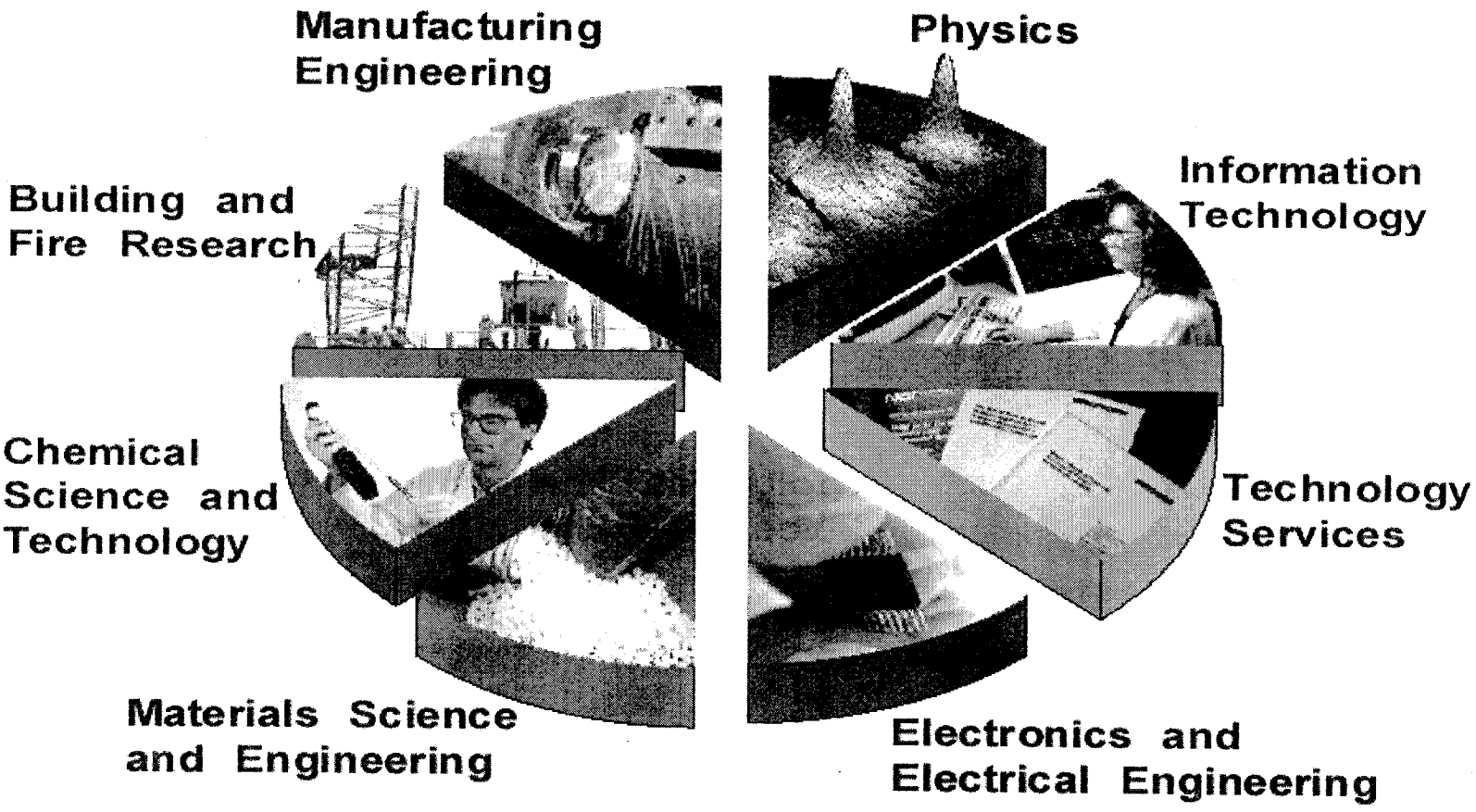
Nation's ultimate reference point for measurements, standards, and technology research to support industry, science, health, safety, and the environment.

Baldrige National Quality Program

Outreach program to promote business performance excellence and quality achievement by U.S. companies. Annual Baldrige awards in manufacturing, ser-vice, small business, education, and health care.

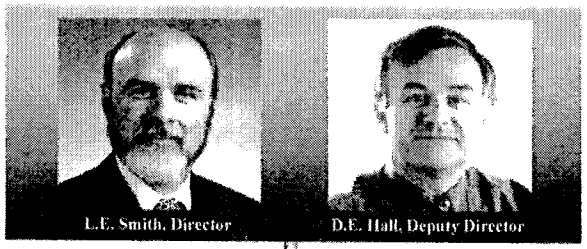
NIST National Institute of Standards and Technology

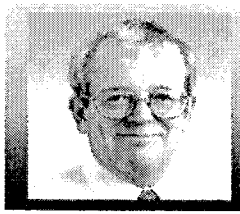
NIST Laboratories



Materials Science and Engineering Laboratory

280 total staff
230 technical staff
400 guest researchers
$45M operating budget
beamlines at NSLS and APS





NIST Center for Neutron Research

J.M. Rowe, Director

- Cold Neutron Project
- Neutron Condensed Matter Science
- Reactor Operations and Engineering

Center for Theoretical and Computational Materials Science

S. Glotzer, Director

Ceramics

E.R. Fuller, Chief

- Microscale Measurements
- Structural Characterization
- Intelligent Processing

Metallurgy

G. Hembree, Chief

- Electrochemical Processing
- Magnetic Materials
- Materials Performance
- Materials Structure and Characterization
- Metallurgical Processing

Polymers

E.J. Amis, Chief

- Characterization and Measurement
- Electronics Materials
- Biomaterials
- Multiphase Materials
- Processing Characterization
- Multivariant Measurement Methods

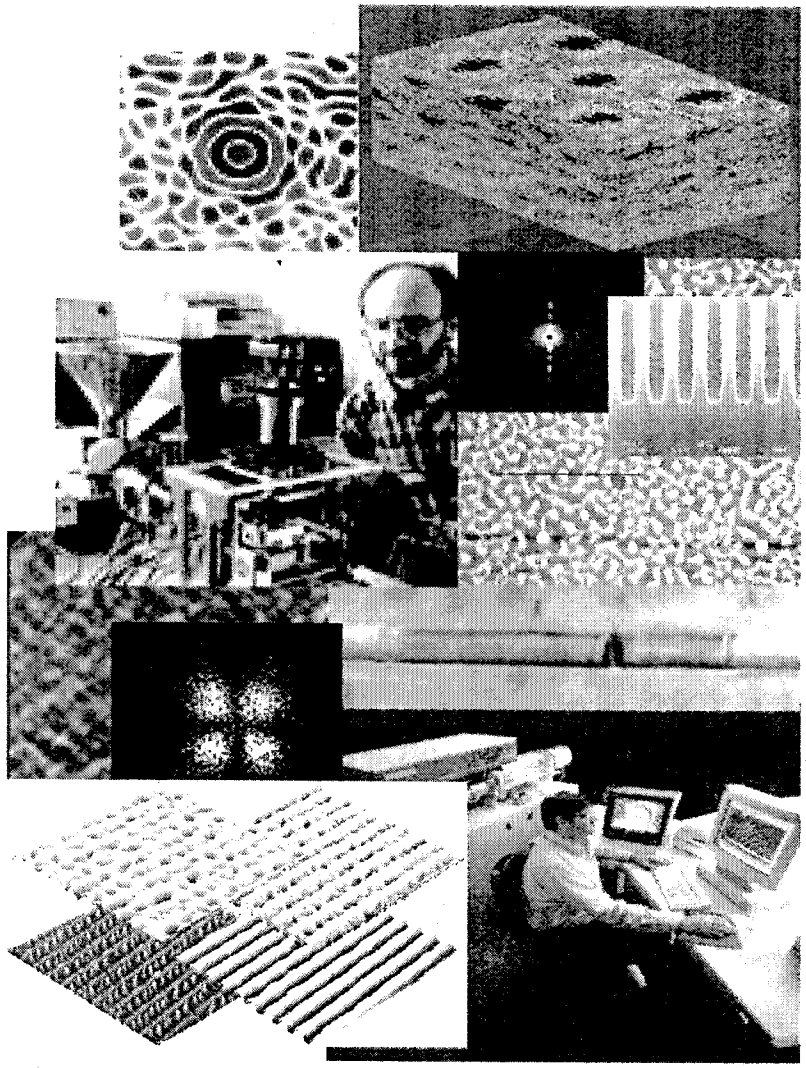
Corrosion

S.W. Freiman, Chief

- Powder Characterization and Processing
- Mechanical Properties
- Film Characterization and Properties
- Materials Microstructural Characterization
- Surface Properties
- Data Technologies

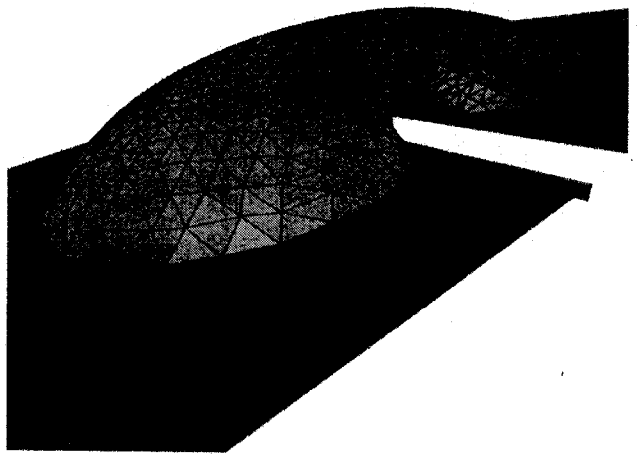
Polymers Division

- Electronics Applications
  - Low-k Dielectric Thin Films
  - Scattering and Reflectivity
- Polymer Blends and Processing
  - Instrumented Extruder
  - High Surface Nanofillers
  - Polymer Interfaces/Interphases
  - Combinatorial Methods
- Polymer Composites
  - Optical Coherence Tomography
  - Microstructure Failure
- Polymer Characterization
  - Matrix Assisted Desorption Mass Spectrometry
- Dental and Medical Materials



Metallurgy Division

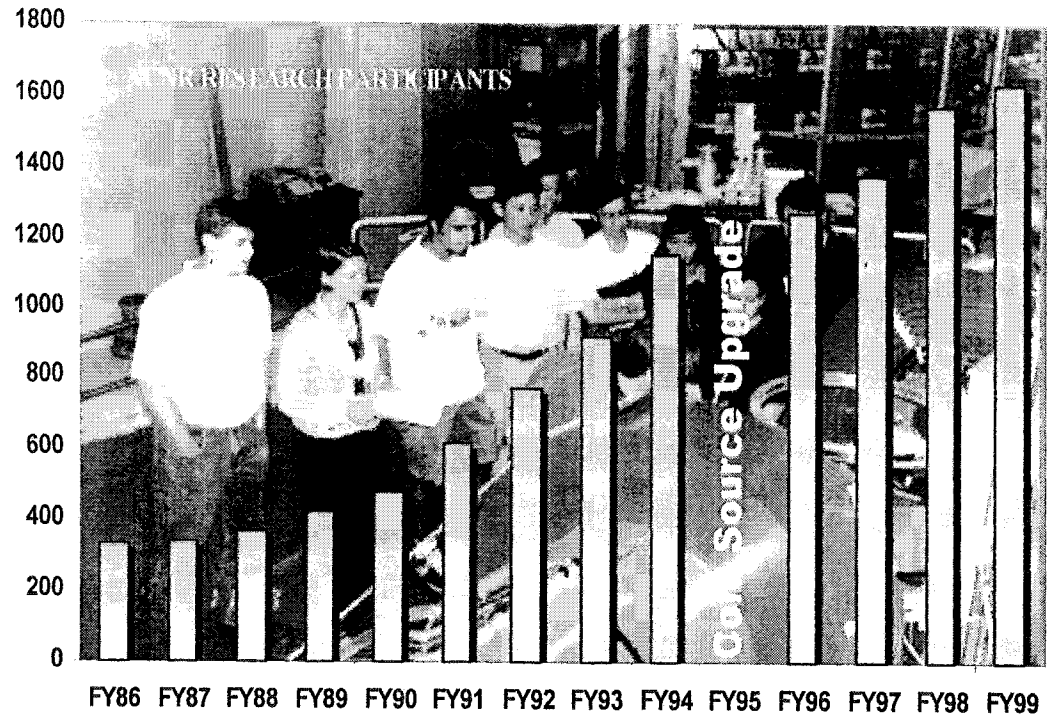
- Electronic Packaging and Interconnection
  - sub-monolayer measurements of copper electrodeposition processes
  - measurements for Pb free solder
  - modeling for solder interconnects, wafer level underfill, and optical interconnects
- Magnetics
  - GMR spin valves
  - magnetic thin film fabrication
  - micromagnetics modeling for domain dynamics
- Surface Engineering
  - in-situ monitoring and control of thermal spray processes
  - thermal and mechanical properties of multilayer materials and coatings
- Thermodynamic and Mechanical Behavior of Materials
  - phase equilibria/processing path data and modeling tools
  - multi-scale measurement and modeling of plastic deformation
  - hardness standards



Ceramics Division

- Thin film functional materials
  - phase content
  - fundamental adhesion measurements
  - thermal measurements
- Informatics
  - ceramic webbook databases
  - MatML common mark-up language
- Ceramics for Wireless
  - phase equilibria and processing path data
  - crystal structure – property relations
  - first principles property prediction
- Nanotribology
  - magnetic hard discs
  - MEMS

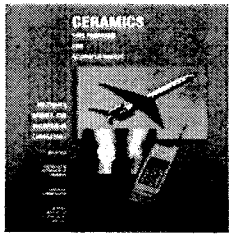
NIST Center for Neutron Research Utilization

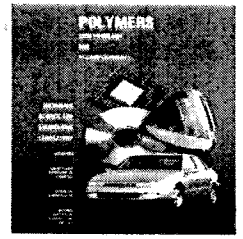


- Most versatile neutron facility in the U S with 35 experimental stations
- Over 1600 annual users representing over 1/2 U S neutron users
- Participants from
  - 55 industrial organizations
  - 34 Government agencies
  - 105 universities
  - 20 NIST Divisions and centers

Recent NIST/NSF Work-shop on the use of high resolution neutron spectroscopies, with total number of research participants superimposed

MSEL Program Structure





Measurement Facilities ($21.7M)
- Neutron Facility Operation
- Neutron Characterization
- Synchrotron X-Ray Beam Lines

Materials Characterization ($5.3M)
- Metals Data and Characterization
- Polymer Characterization
- Ultrasonic Characterization

Structural Materials ($2.7M)
- Polymer Composites
- Failure of Brittle Materials

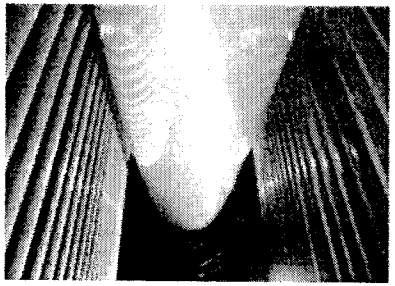
Materials Manufacturing ($12.2M)
- Metals Processing
- Polymer Blends and Processing
- Phase Equilibria
- Ceramic Manufacturing
- Ceramic Coatings

Functional Materials ($2.7M)
- Electronic Packaging
- Thin Film Measurements
- Magnetic Materials
- Dental and Medical Materials

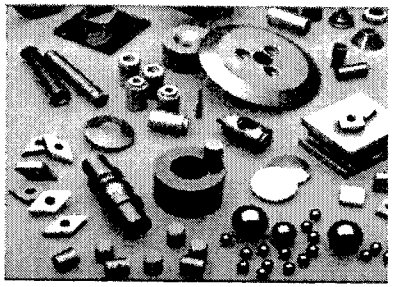
MSEL Industrial Customers

Materials Producers

Steel and Aluminum



Plastics and Rubber



Advanced Ceramics

Materials Processors

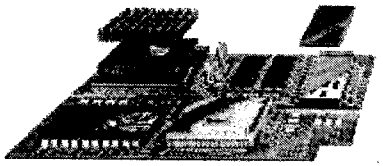
Composites

Welding

Forming

Molding

Materials Users



Microelectronics

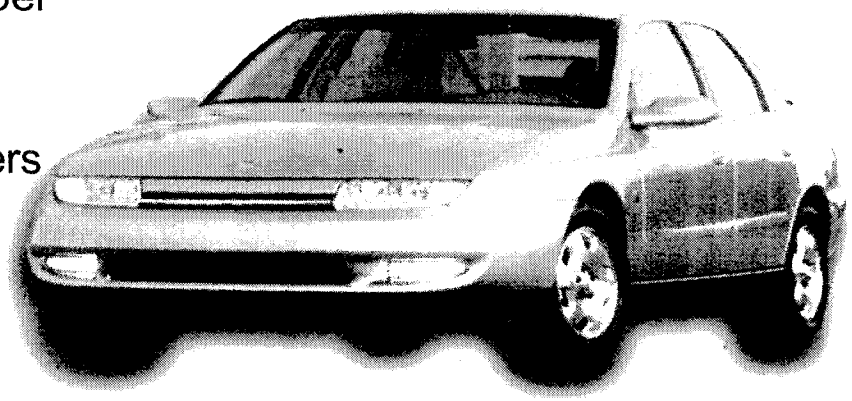
Medical and Dental Instruments and Supplies

Automotive

NIST National Institute of Standards and Technology

MSEL Research Supporting the Automobile Industry

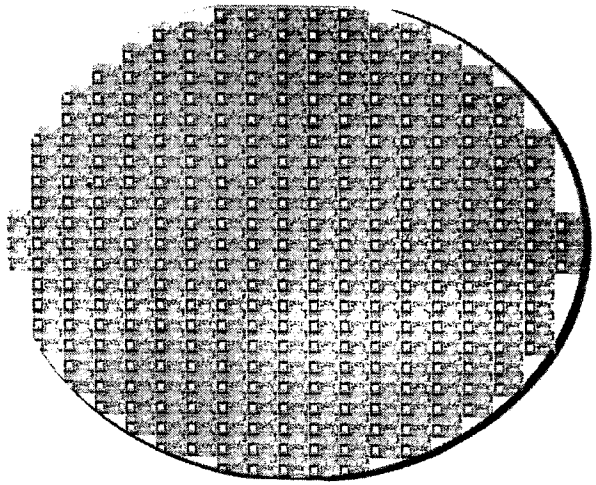
- Polymer phase behavior for synthetic rubber blends
  - improved skid resistance for tires
  - maximum energy absorption for bumpers
- Measurements for autobody sheet metal forming
- Sensors and diagnostics for plasma spray coatings for engine cylinders and weld filling
- Coating thickness standards for painted and galvanized autobody sheet steels
- High temperature, fatigue resistant solders for under-hood use
- Measurements and data for machining of ceramic parts



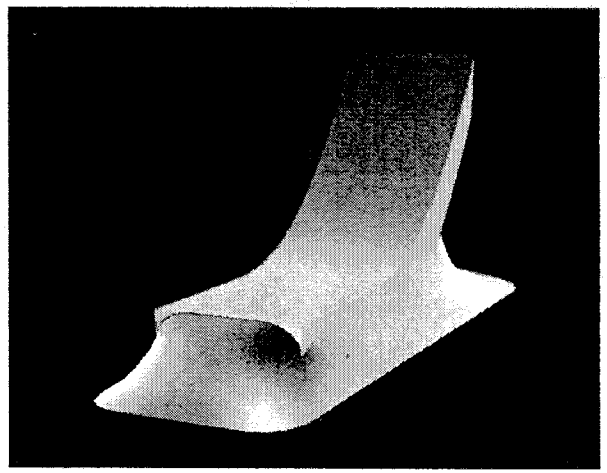
- Compaction of metal matrix composites for drive-train components
- Conduction dynamics of high-temperature protonic conductors for lightweight batteries
- Modeling of molding of polymer composites

MSEL Research Supporting the Electronics Industry

- Standard microelectronics test structure produced for embedded capacitors
- Data on critical properties of low-k dielectrics provided to SEMATECH
- Measurement method for CTE of thin interlayer dielectrics developed
- Software for solder interconnect design developed and delivered to industry
- Environmentally friendly lead-free solder alloys characterized for manufacturability and performance
- Promising ceramic phase diagrams completed for potential wireless use
- Data on high Tc materials made available on WWW



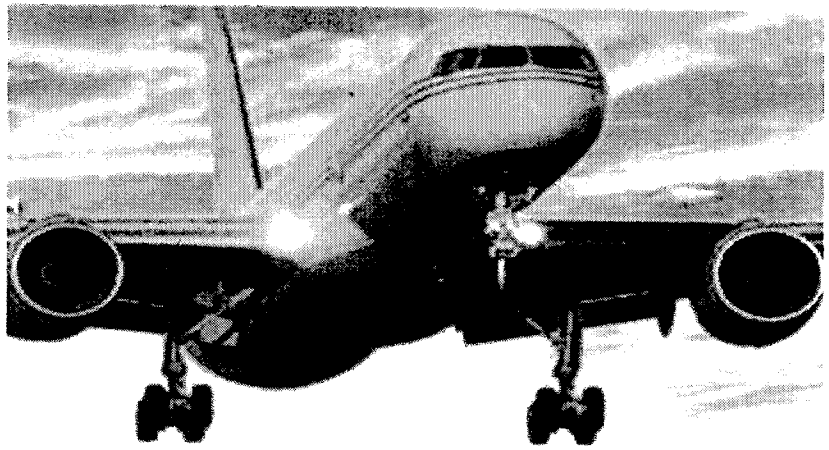
Development of Alternatives to Lead-Containing Solders



- Industry need: Identification of alloy compositions that meet toxicological, economic, manufacturing, and reliability criteria
  - NIST provides phase diagram calculations and analysis and correlations with critical properties to assist in materials selection
- Industry need: Tests for fillet lifting, new failure mode with lead-free solders in through-hole applications
  - NIST provides strategy for developing and analyzing quantitative laboratory scale tests, including error analysis, for fillet lifting. Identified root cause as hot tearing during solidification and determined effects of alloy composition

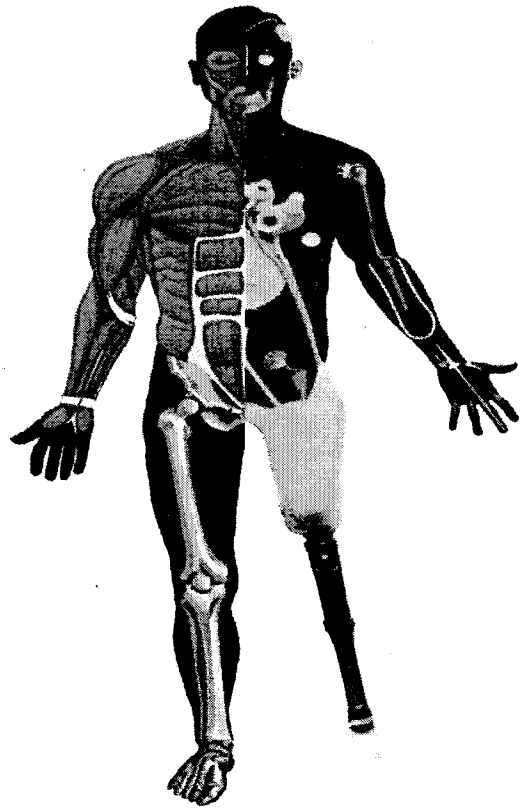
MSEL Research Supporting the Aerospace Industry

- NIST Consortium for the Casting of Aerospace Alloys
- High temperature thermo-physical measurements of thermal barrier coating
- Sensors and diagnostics for plasma spray coatings
- Phase diagrams for transient liquid phase bonding of engine components



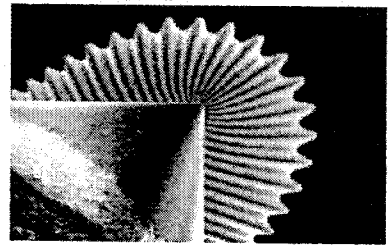
MSEL Research Supporting the Dental and Medical Industries

- Wear measurement for artificial joint materials
- Dilatometer to measure shrinkage of dental resins
- Fluorescent probes for cure monitoring of dental bonding resins and bone cements
- Silver-based dental restoratives to replace amalgams
- Mechanism of failure in ceramic restorations
- New dental composites with durability, color stability



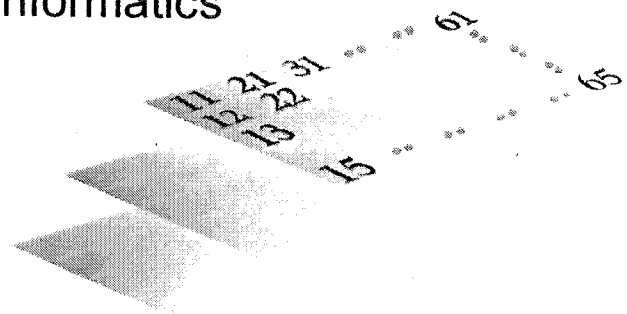
Emerging Technologies

Sensors

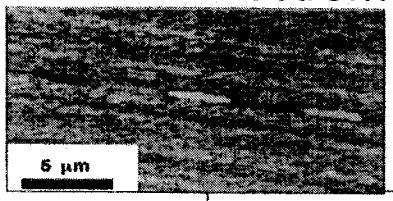


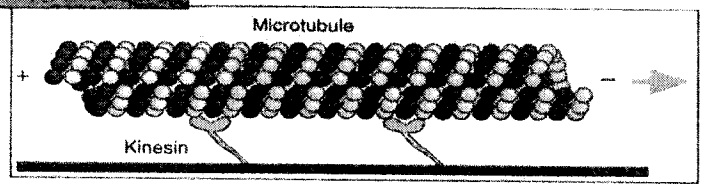
Rapid Prototyping

Informatics

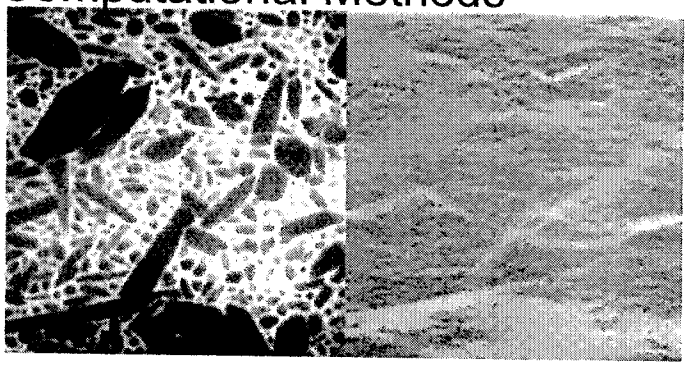


Bio-Microelectromechanical Systems

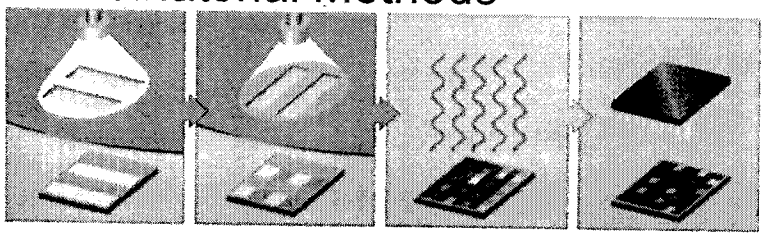


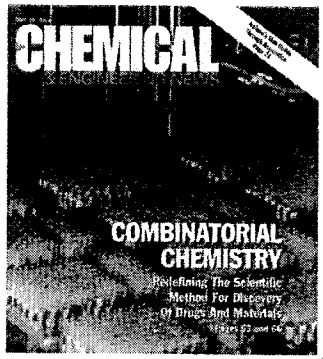


Theoretical and Computational Methods



Combinatorial Methods





special report

Materials À La Combi

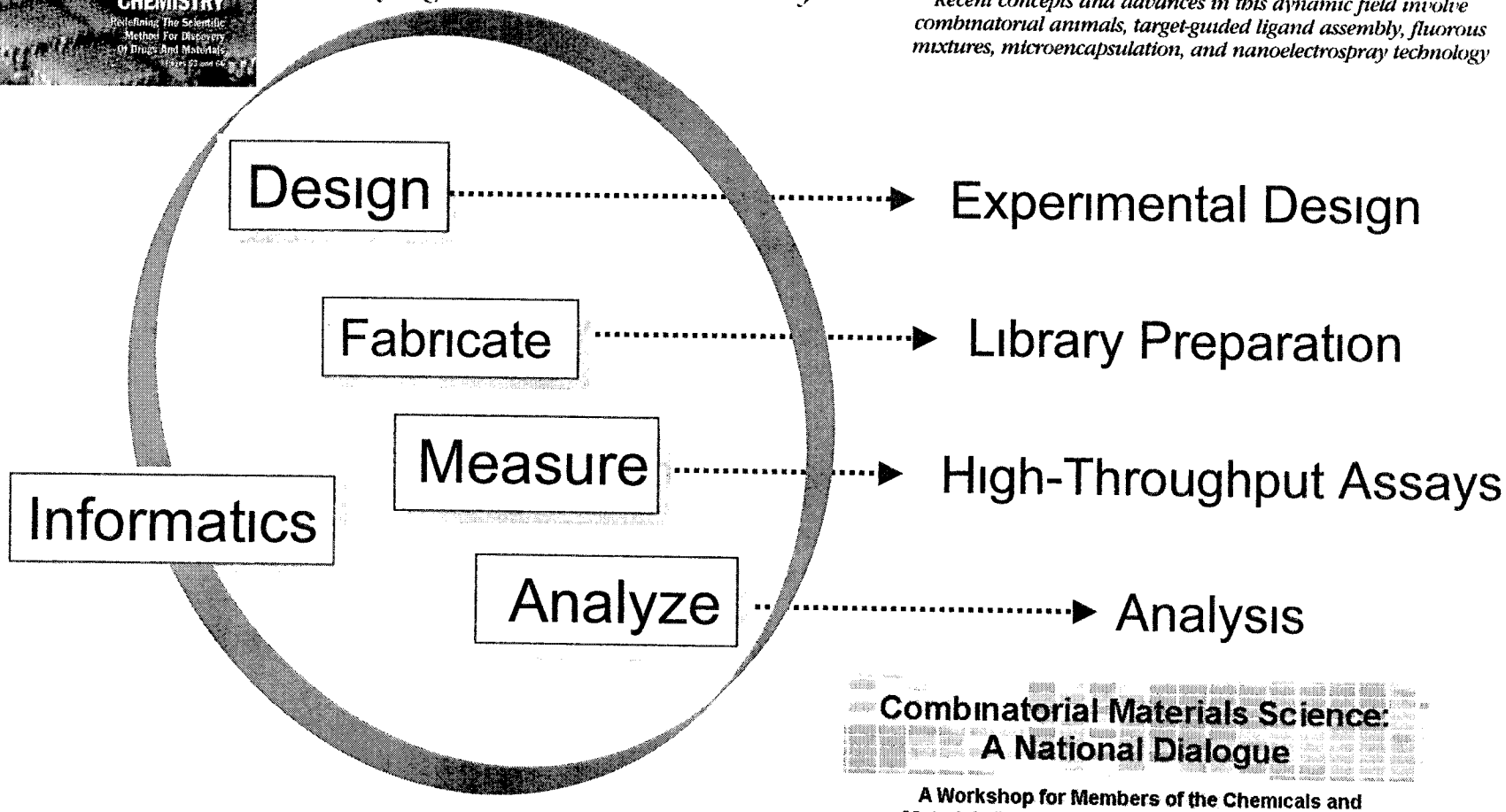
Despite the challenges, a growing number of corporate and other labs see promise in studying materials combinatorially

special report

COMBINATORIAL CHEMISTRY

Redefining The Scientific Method

Recent concepts and advances in this dynamic field involve combinatorial animals, target-guided ligand assembly, fluorous mixtures, microencapsulation, and nanoelectrospray technology



Combinatorial Materials Science: A National Dialogue

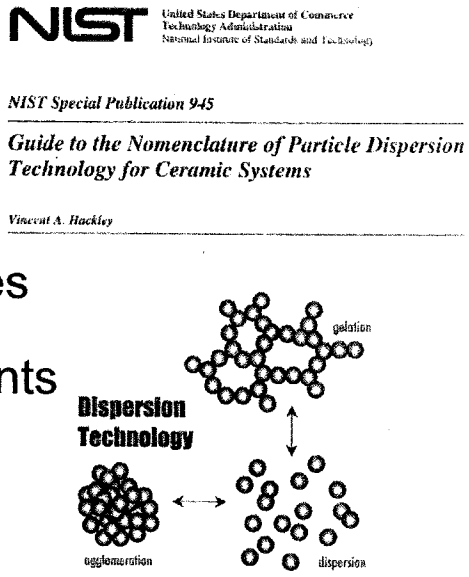
A Workshop for Members of the Chemicals and Materials R&D Enterprise from Industry, Academia, and Government

Gaithersburg, Maryland
May 31 – June 1, 2000

NIST National Institute of Standards and Technology

Recommended Practice Guides

- Insure proper application of our measurement technology
- Guides planned for 2000 include:
  - Ceramic Particle Size Measurements
  - Design with Brittle Materials
  - Installing, Maintaining, and Verifying Impact Machines
  - Measurements of Permeability of Fiber Reinforcements for Polymer Composites
  - Rockwell C Hardness Standards
  - Coating Thickness Standards
  - Introduction to the Use of Neutron Diffraction



Measurement Services Programs
Standards - Related Activities

Reference Materials

- SRM program is the second most active at NIST
  - 88 currently on sale
  - 4205 units sold (FY 99)
  - more than 66K sold since 1982

Impact Tests
Particle Size
X-ray Diffraction

Reference Data

- 7 databases on materials' properties

Inorganic Crystal Structure Database
> 50,000 inorganic compounds

Metals and Ceramics
Phase Diagrams
Corrosion

National and International Standards

- 25% of MSEL professional staff hold 182 standards committee memberships
- 25 committee or subcommittee chairs

Best in the World Capabilities

- **Phase Equilibria**

  Best in the World:
  - evaluated ceramic phase equilibria data
  - application of alloy phase diagrams
  - polymer phase behavior under shear
  - kinetics of phase transformation in polymers

  Among the Best in the World:
  - modeling of complex oxide systems
  - generation of alloy phase diagrams

- **Magnetic Materials**

  Best in the World:
  - thin film synthesis facility
  - measurement of absolute values of magnetic moments
  - magnetic property determinations by neutrons

  Among the Best in the World:
  - nanophase magnetic materials
  - micromagnetic modeling

- **Neutron Measurements**

  Best in the World:
  - neutron reflectometry
  - neutron interferometry
  - neutron depth profiling & prompt-gamma spectroscopy
  - ultra-high resolution back-reflection spectroscopy

  Among the Best in the World:
  - small-angle neutron scattering
  - neutron inelastic scattering
  - high-resolution powder diffraction
  - conventional neutron activation analysis
  - magnetic property determination
  - sub-surface residual stress

Center for Theoretical and Computational Materials Science Profile

- Created in 1995 to provide new outlets for strong NIST capabilities in materials theory and computation
- A "distributed" center
  - uses recent advances in computing and communications
  - operates a highly interactive web site
- Goal: application of materials theory and modeling to solve industrial problems in materials design and processing

CTCMS Approach

- Identify important problems and key participants via workshops
- Form multi-lateral working groups
- Pursue research defined by the group
  - workshops for hands-on collaboration, information exchange and steering
- Transfer technology via personal interactions, publications, tutorials, website, presentations

CTCMS 1999 Technical Focus Areas

- Object Oriented Finite Element Modeling of Composite Materials
  - develop an easy-to-use computational tool for analyzing microstructure and calculating macroscopic properties from micro-graphs of composite materials
- Green's Functions Library for Materials
  - develop an interactive, electronic library tool consisting of Green's function and boundary element solutions for standard material geometries arising in elastostatics, elastodynamics, acoustics and ultrasonics.
- Micromagnetic Modeling
  - develop interactive computational tools for micromagnetics modeling, provide solutions to standard problems, and conduct benchmark verification.
- Wulffman
  - develop an easy-to-use software tool for building equilibrium crystal shapes.
- Modeling of Multi-phase Polymer/Liquid Crystal Blends
  - improve properties of multi-phase materials used in displays and information technology through modeling of morphogenesis

CTCMS 1999 Technical Focus Areas (cont...)

- Solder Interconnect Design Team
  - develop and evaluate computational methods and software tools for modeling geometries in solder interconnects to improve industrial electronic packaging processes.
- Deformation
  - predict mechanical response of plastically deformed metals from theoretical models of the underlying dislocation structures which evolve during deformation.
- Theory and Modeling of Glass Forming Materials
  - measure and characterize microstructure and dynamics of heterogeneities of disordered and partially ordered materials to improve understanding of glass forming materials.
- Solidification
  - to develop models of solidification processes. To better understand the physics of solidification and predict the microstructures which emerge during solidification.

USING MST-ONLINE TO IMPROVE INSTRUCTION

James A. Jacobs

Department of Technology
Norfolk State University
700 Park Avenue
Norfolk, Virginia 23504-8060

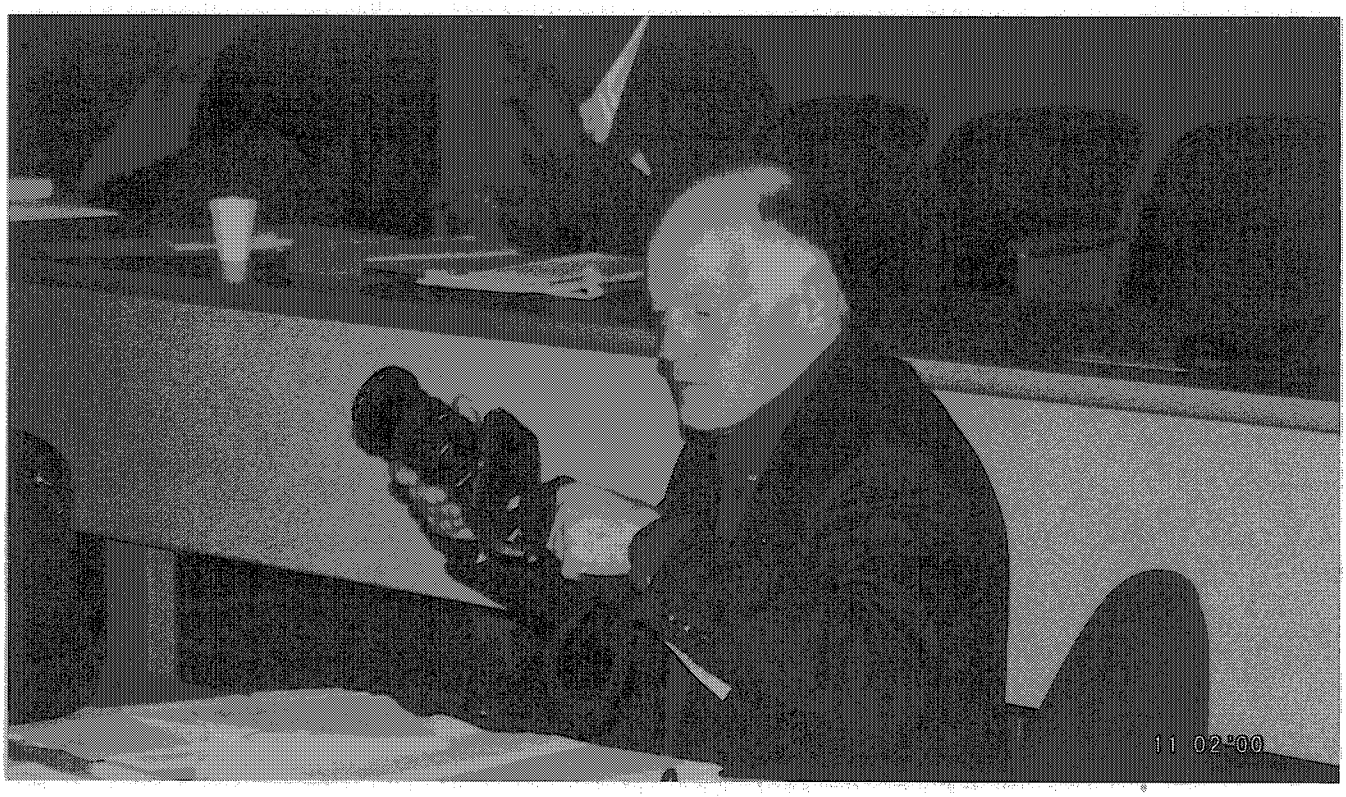
Telephone: 757-823-8109
e-mail jajacobs@nsu.edu

and

Curtiss E. Wall

Norfolk State University
700 Park Avenue
Norfolk, Virginia 23504

Telephone: 757-823-9571
e-mail cewall@nsu.edu



James A Jacobs

Curtiss E Wall

Using MST-Online to Improve Instruction

James A. Jacobs and Curtiss E. Wall
Norfolk State University
Norfolk, VA 23504

Key Words: Computer, Internet, CD-ROM.

Prerequisite Knowledge: Basic computer literacy and use of the World Wide Web.

Objectives: To use the gateway web site < Http://MST-online.nsu.edu > for introductory concepts on materials, science, and technology. To make links to materials science and technology educational resources, including materials research efforts from national labs, universities, and corporations as well as to technical societies and educational institutions that have web sites with downloadable instructional resources.

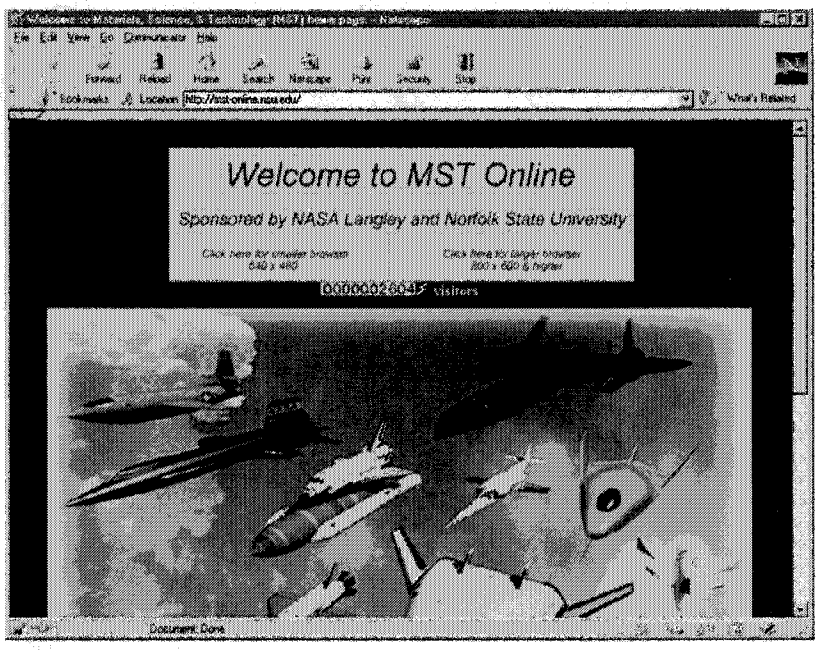
Equipment and Supplies: An Internet connected computer. A computer running at least 500mhz with a 800 x 600 screen is preferred.

Introduction: Beginning in 1990 with a grant from IBM Corporation, we have been using computers to enhance technology instruction at Norfolk State University (NSU). In 1998 we conceived the idea of expanding our efforts into the world wide web (www). We planned to develop a site that provide educational resources in math, science and technology (MST) built around materials science and technology (MST). We developed the site as a "gateway website" or portal. The site provides basic MST concepts that link to federal laboratories, technical societies, other universities, and corporations.

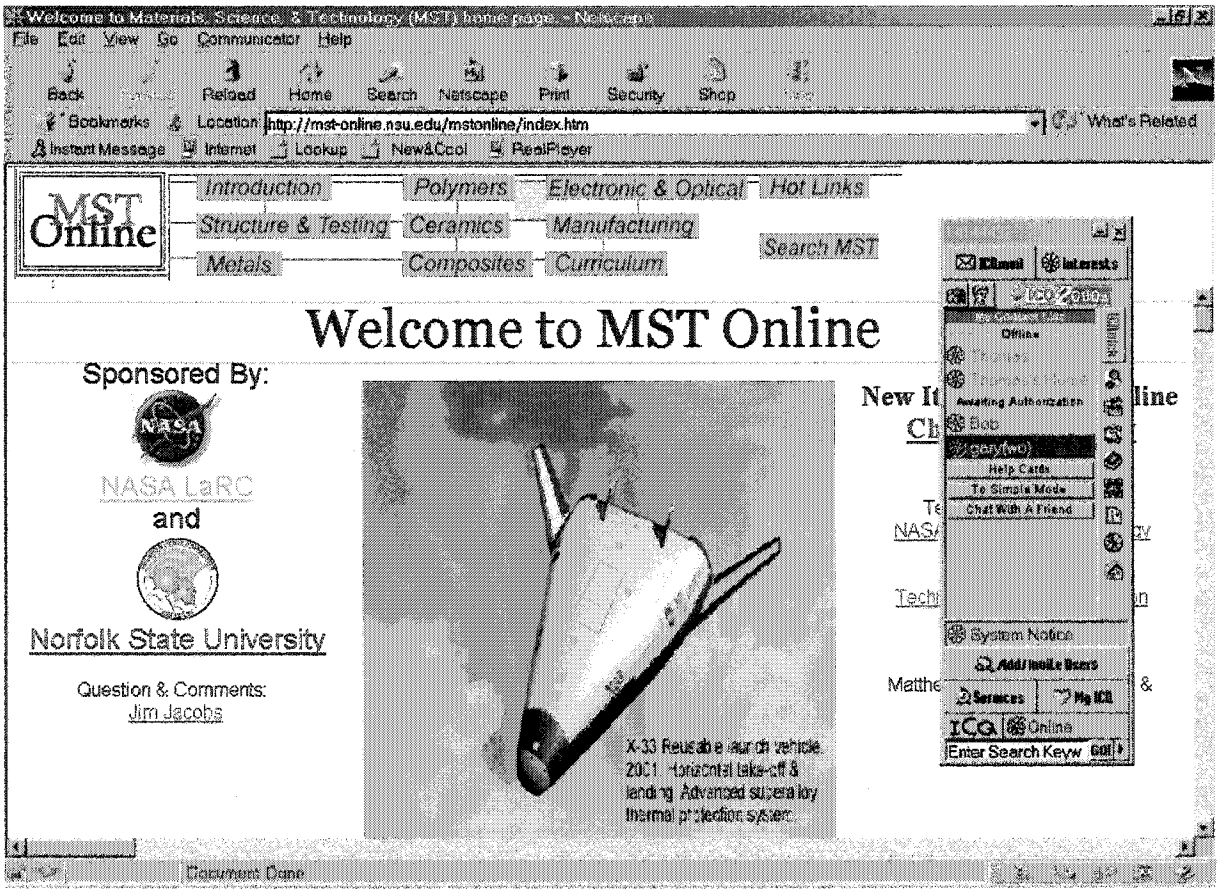
The basic concepts build on the textbook, *Engineering Materials Technology*, by James A. Jacobs and Thomas F. Kilduff. To graphically augment those concepts, we obtained images from numerous sources including museums, NASA, technical societies, manufacturers and fellow educators.

With support from NSU and NASA Langley Research Center, we were able to build MST-Online. MST-Online can serve as your portal to web based materials education.

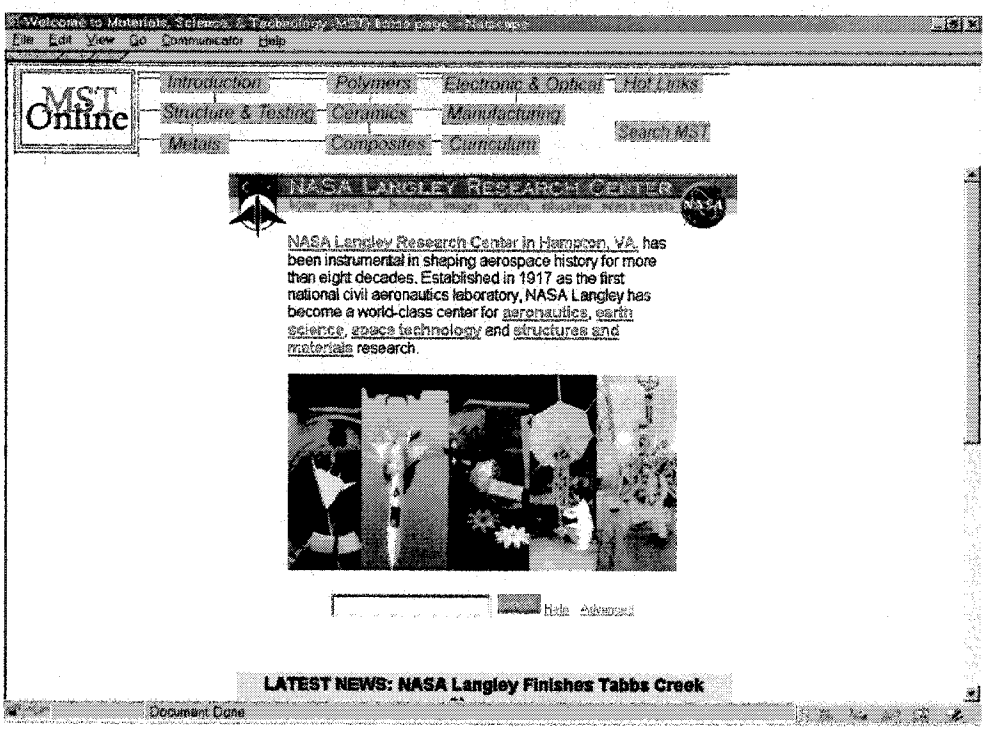
Procedure: Open up your web browser and type *mst-online.nsu.edu* on the line reserved for the url or uniform resource locator. The home page for mst-online should appear.

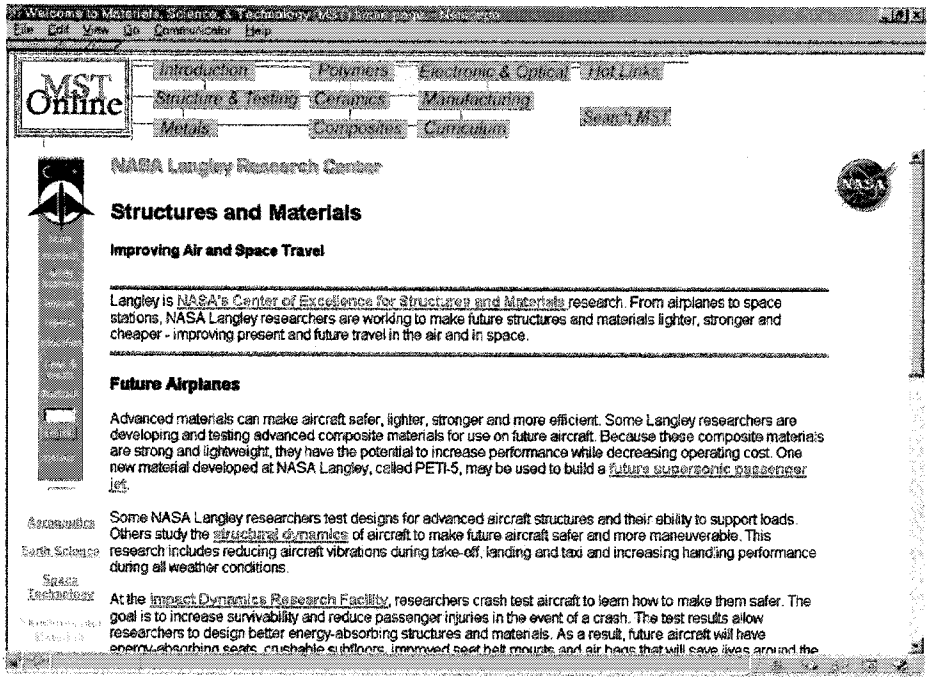


Move your mouse to the area of the page containing the appropriate screen size and press the left mouse button. The main menu page should appear.
You are now ready to use the resources of mst-online. At that point you can directly link to the sponsors. Click on NASA Langley to gain access the their site,



then click on structures and materials research to get into NASA's Center of Excellence for Structures and Materials.

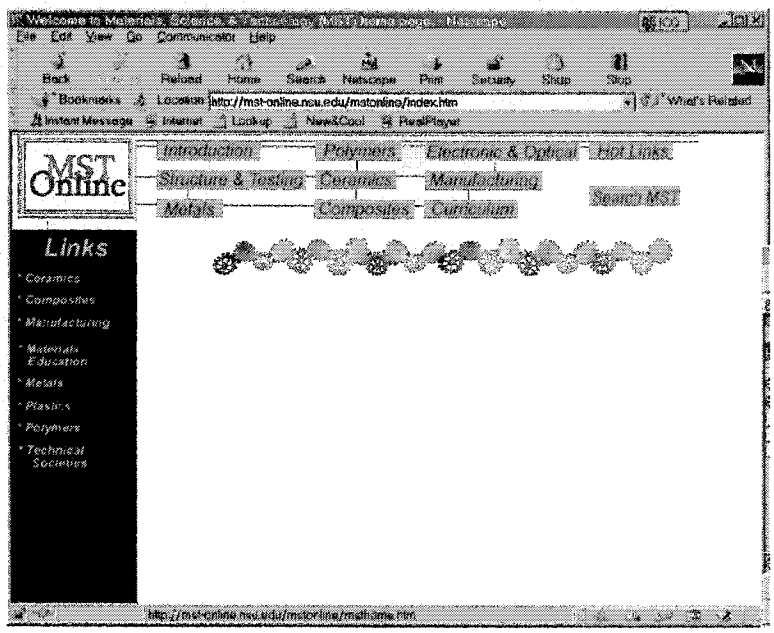


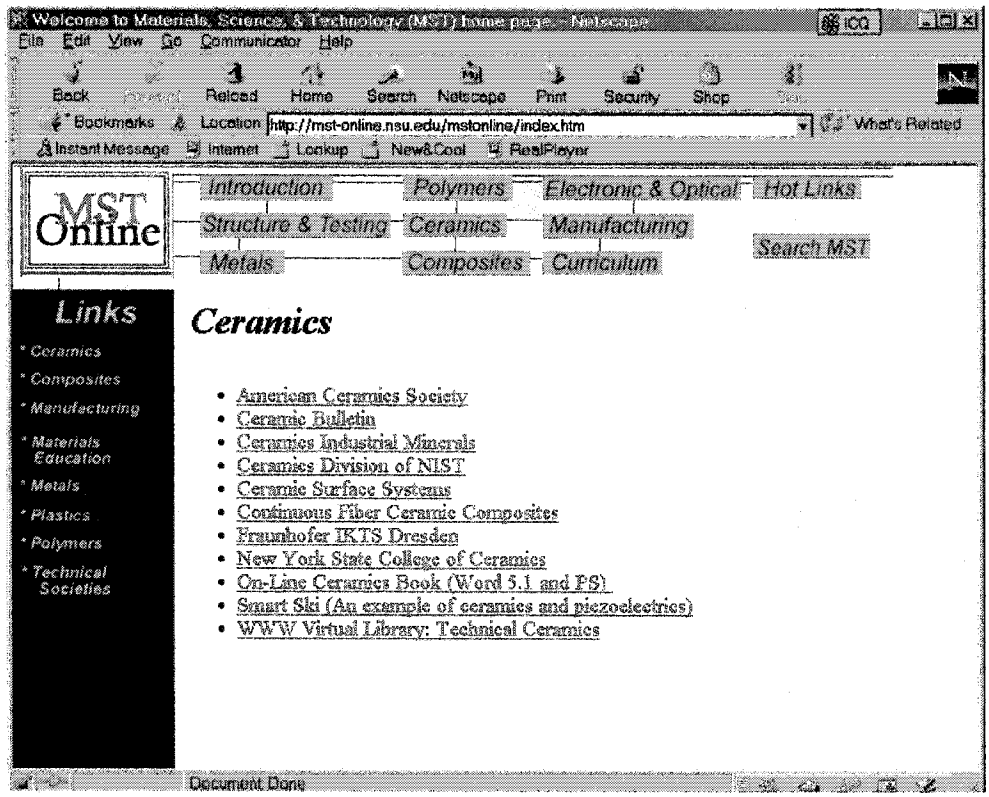


Notice that the MST-online menu is still at the top of your screen. If you click on Hot Links

Hot Links you will

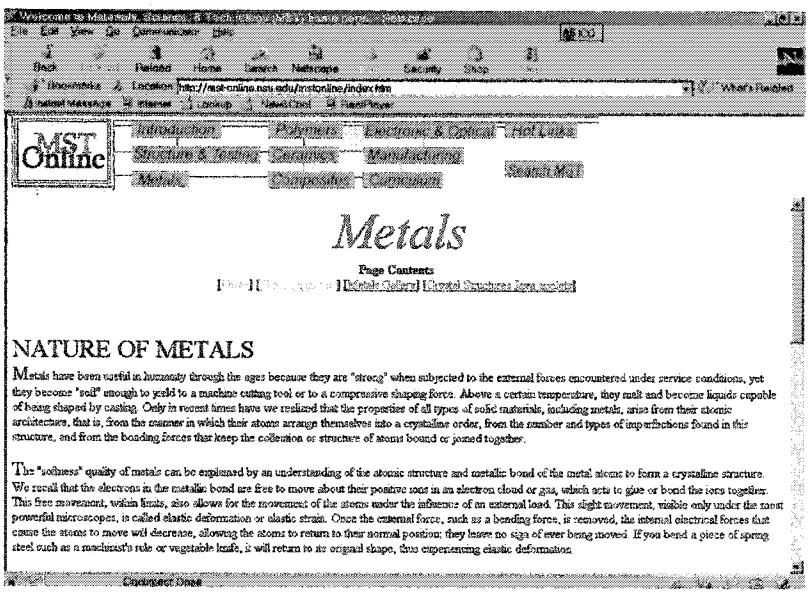
be taken to the page that connects to external links. Each area has its own button to access a page of links. For instance, if you click on ceramics, the following page will be displayed.





MST-online has a valuable set of reference material for you to access. If you select one of the other items from the menu at the top of the screen such as Metals *Metals* you will be taken to a section in the *Engineering Materials Technology* book on metals. At this point you

are presented with a frame containing the main menu at the top of the page, an introductory page in the frame at the bottom of the page. On the introductory page there is a sub menu for exploring different aspects of the main topic.



Throughout MST-Online diagrams and pictures are available for examination. If we choose Phase Diagrams under Metals, a new page will be presented. This page, dealing with phase diagrams, has more detailed information, including a line which displays a link to Figure 5-9 . Clicking on that link will bring up a unary phase diagram of water. This diagram is displayed directly below the web page for Phase Diagrams.

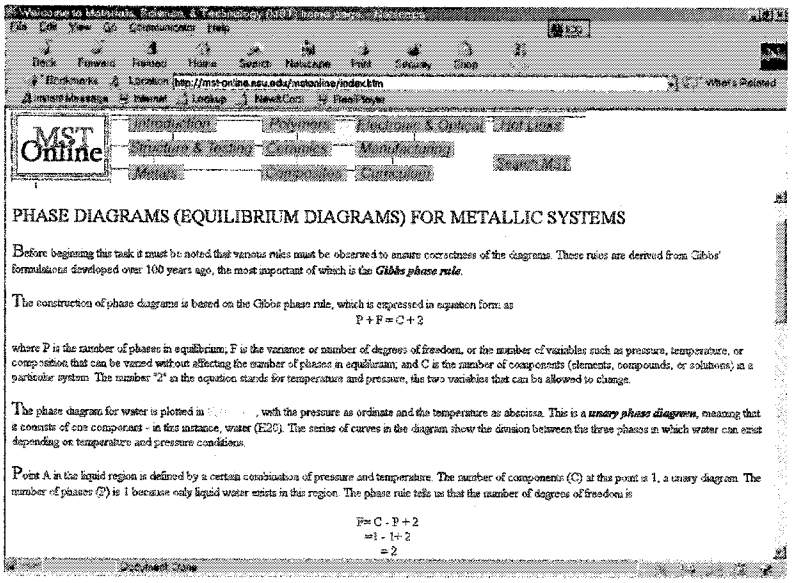
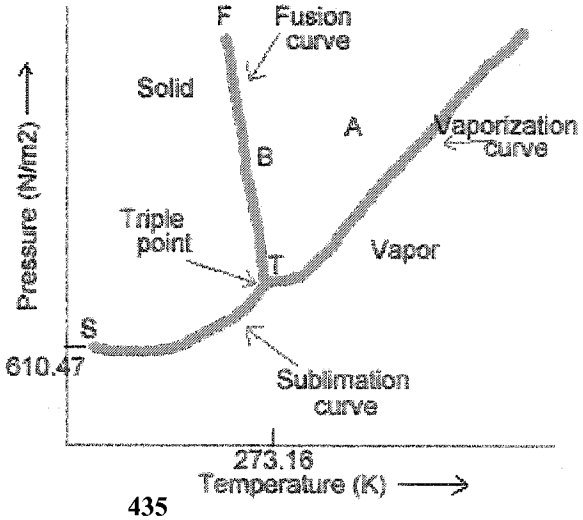


Figure 5-9 Unary phase diagram for water



Conclusion: The use of the world wide web to access information not otherwise available to students is exciting in itself. However, the real revolution in education may be the use of hyper links to present this information in new ways. Certainly, Apple's hyper book and Toolbook and Linkway for DOS computers were the beginning of this innovation, but the combination of hypertext tools and the vast amount of information stored on computers throughout the world will revolutionize our teaching. In the future, the use of streaming video and audio will further expand the potential of this learning tool. We should remember that this is only one tool that we are able to employ, and hands on learning is still an important component of the learning process. As a gateway website, MST-Online provides the portal to many other sites. The dynamics of the Internet is such that these sites should be constantly providing fresh information and instructional resources for you and your students.

THE BLACK BOX

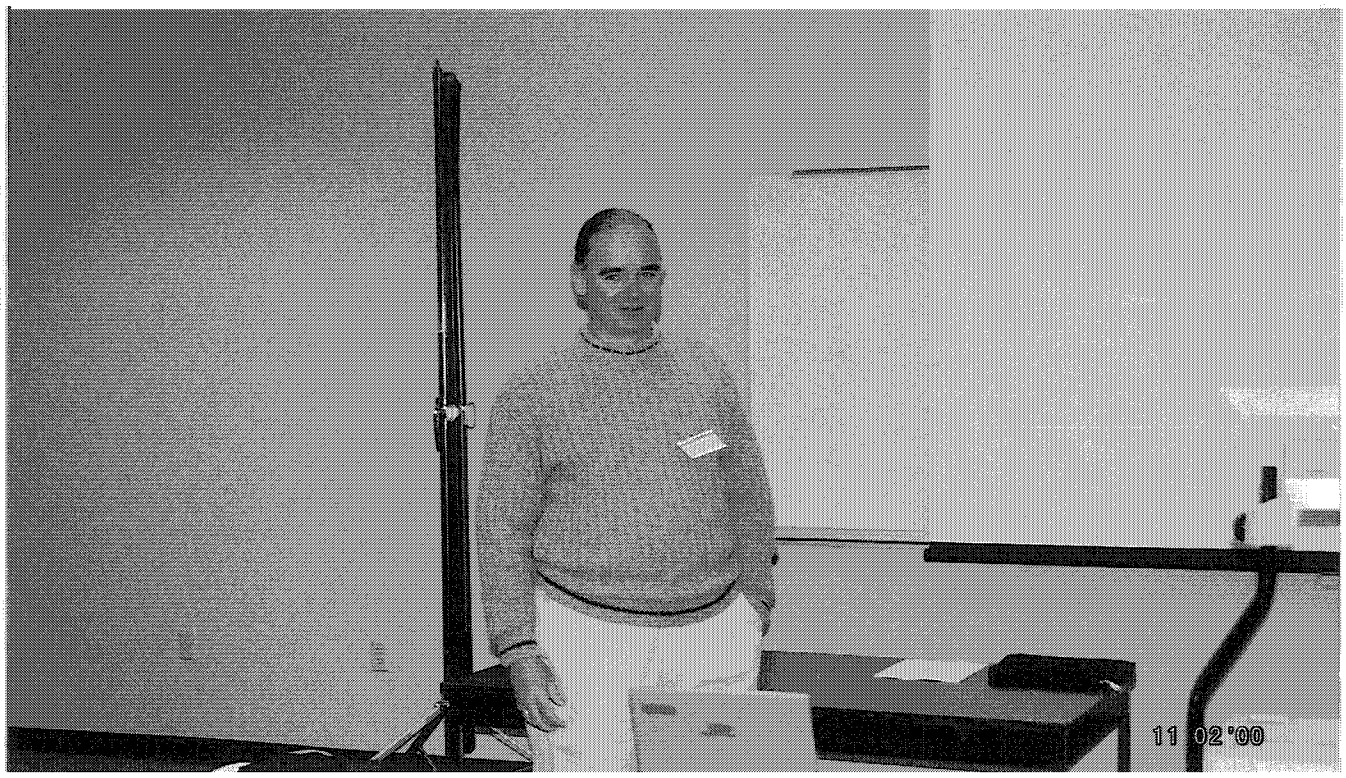
Mike L. Meier

Department of Chemical Engineering and Materials Science
University of California, Davis
Davis, California 95616

Telephone: 530-752-5166
e-mail mlmeier@ucdavis.edu

Biography:

Michael L. Meier received his B.S in Materials Engineering from North Carolina State University in 1979 and his M.S. (1986) and Ph D. (1991) in Materials Science and Engineering from the University of California, Davis. After a two-year post-doctorate position at the Universität Erlangen-Nürnberg in Erlangen, Germany he returned to UC Davis where he is the director of Materials Science Central Facilities and teaches many of the laboratory courses



THE BLACK BOX

Mike Meier
Department of Chemical Engineering and Materials Science
University of California, Davis
Davis, CA 95616
USA

Key Words: theory, hypothesis, scientific method

Prerequisite Knowledge: none

Objective:
In this experiment the student is given a closed, sealed black box which contains one or more small objects. The immediate goal is to figure out what is inside the box. The ultimate goal is to get one's colleagues to concur. The overall objective is to learn something about science and to initiate a discussion of the nature of science.

Equipment and Materials:
1. Black boxes (Radio Shack part 270-1807)
2. Simple objects to put inside the boxes, such as nuts, bolts, ping pong ball, twigs, dice, wood blocks, coins, rubber ball.

Introduction:
The goal of science is the acquisition of new knowledge. But there are rules, rules which tend to make science seem cold and impersonal, and there is a process, something which tends to make science appear to be the boring domain of eggheads. But to those who "do" science it is a series of puzzles to assemble, discoveries to be made, a grand quest to understand our universe. This experiment is designed to give you an introduction to the rules and the process, and a taste of what it is like to participate in this quest. The books listed in the references offer additional perspectives, both amusing and very serious, on the goals, nature and issues confronting modern science.

Science is a social activity practiced by individuals, groups and nations. It is essentially a debate in which theories, hypothesis, experiments, objective observations, things people associate with science, are merely elements. As a debate it is very demanding, with some hard rules and strict requirements: rigorous logic, testable hypothesis, and most of all the requirement that you must be able to back up your claims with hard evidence.

It may seem that there are different sorts of science. In some fields, the thing being studied can be held in your hand, poked and prodded, and disassembled on the laboratory bench. In others it may be trillions of miles away and billions of years in the past. In geology, the earth itself is the specimen and the processes being studied may require from seconds to eons to run to completion. In the social sciences the "specimens" are so complex that it seems unlikely that they will ever be able to enjoy the level of success enjoyed by the physical sciences. Some science is data-driven,

others theory-driven. Some sciences are quantitative while others are mostly qualitative; some are data-rich and others data-poor. Furthermore, the tools and methods the scientist uses can be as unique as any particular investigation, as unique as each scientist, and as unique as the field of study.

The Experimental Method: One might say that science is a product of the experimental method, the process of isolating the variables important to the study and investigating the relationship of each variable to the phenomenon in question. This is indeed one of the main tools of scientists and it has also provided us with sound theories that can explain the nature of extraordinary things we deal with in everyday life, things we will never be able to see with our five senses, but theories so convincing, so well explained and so well supported by experiment and employed in things we use everyday that we may have come to think of as ordinary.

Scientific Theory: The product of science is the scientific theory. A theory is a statement that attempts to explain the nature of something. It is the end product of a series of tests performed that prove or disprove a series of more general statements, or propositions (hypotheses). It is not, as many people tend to think, a guess.

Most scientists will agree that for a theory to be considered a scientific theory it must possess the following characteristics:

- Falsifiability, or refutability, or testability
- Supported by the evidence
- Makes predictions

Besides defining scientific theory, these three requirements place restrictions on the things that can be investigated scientifically. Many questions simply can not be answered by scientific investigations.

The Scientific Method: Many of us have been taught that the scientific method involves the following:

- Select something in nature to study
- Develop hypotheses about how it works or how it relates to other things
- Pursue this hypothesis until it yields unique and testable predictions
- Test the hypothesis
- Repeat, refining the hypothesis until a theory can be formulated

In practice, the actual method of doing scientific is hardly as neat and tidy as the one described above. While the process of acquiring this new knowledge almost always requires careful, focused effort, scientific discoveries may also involve luck and even fortuitous accidents, or a unique way of looking at things, or knowledge and experience that few other people have. So while it may seem like a grand personal adventure while you are "doing" science, it becomes a public debate when you publish it.

The Scientific Publication: The appearance of tidiness in the scientific method can be blamed on

the published scientific paper. In it one describes the evidence, the methods and observations in clear, concise and logical manner so as to build a solid argument that supports your conclusions. In these papers one does not describe the accidents, the dead ends and the early mistakes that produced no results. The scientific publication also tends to make science appear cold, dry and impersonal. But as mentioned above, doing science isn't cold, dry and impersonal, and scientists aren't, but the results must be.

Each author is aware that the publication is not only an announcement of new findings, it is also an invitation to one's peers to criticize the work. And they will. It is not fun to have one's own theory, the product of hours (or years) of work, shot down in flames in a public arena. But when it happens it is both necessary and healthful. And always remember, the burden of proof is always on the author a fact that makes doing science as difficult and demanding as it is rewarding.

Procedure:

Testing: Examine the box. Find out what you can about the box and then devise ways to determine what is inside the box. Once you have made a few observations you will be able to formulate an initial hypothesis. With further testing you will be able to refine your hypothesis until you have learned as much as you can about the object in the box. While you are not allowed to open the box, you are welcome to use any tool and instrument in the laboratory to help gather the information you need to be able to make a final, definitive statement as to what the object is.

The Results: What do your tests indicate regarding the mass, size, shape, material and other properties of the object in your black box? What do your tests tell you about the black box itself? What do you think the object is?

The Report: Now that you have decided what the object probably is, you'll need to write a formal report that tells your peers about your investigation and how you determined what the object is. Before you start writing, review the goal of the experiment. A well thought out and well stated objective is essential to the writing process and for the reader's understanding of your report. Next, review each of the tests you performed and the information you got from each. Using this information, develop the argument for the conclusion you will make. Finally, state clearly what you think the object is, if you can. Now, write it up.

Peer Review: Share your report with your colleagues. Loan them your box and watch them do the same experiments you did, using your report as a guide. Or maybe they will use the techniques they used when studying their box and will be able to teach you something new about your mystery object. If your colleagues agree with you, well that is reassuring, but there still remains a certain amount of uncertainty as to what the object or objects really are. That is one of the characteristics of even the best of theories. If, on the other hand, someone disagrees and can show you good evidence that is contrary to your findings, errors in your logic, or can offer an alternative explanation that is consistent with your observations, then that when the fun really begins.

Comments:

Our students seem to enjoy this experiment. After shaking and tipping their box a few times they become hooked and are determined to figure out what is in the box. The mood changes, however,

after being reminded that they have to write up their findings. They start taking notes and start trying to be a little more systematic in their investigation. At this point I like to point out that many investigations may start out poking and prodding and just trying different things in an effort to try to get a handle on the problem.

After the students turn in their reports I ask them if their account of the experiment presents the procedures, results and explanations in a clear, concise and logical manner and if it makes a convincing case for what the student thinks the object is. The answer is usually yes, or something close to yes. Then I ask them is their report accurately depicts how the study was actually done. The answer is usually no.

We often conclude that there are several dimensions to doing science and that the finished product may look a lot neater, tidier, impersonal and even more boring than what actually happened. We may eventually get around to talking about how important it is to know as much as possible about the subject before starting a study, but at the same time how those things that make each of us unique can make a real difference, and that everyone brings something different to science. We may conclude the experiment with a discussion of the importance of peer review, and finally I recommend a few books (see references) that they offer fun and interesting perspectives on science.

References:

1. I.Amato, Stuff, The Materials the World is Made Of, Avon Books, Inc., (1997).
2. J.Hatton and P.B.Plouffe, Science and Its Ways of Knowing, Prentice Hall, New Jersey (1997).
3. A.Cromer, Uncommon Sense, Oxford University Press, Inc. (1993).
4. A.K. Dewdney, Yes, We Have No Neutrons, John Wiley and Sons, Inc., New York (1977).
5. W.Hartston, Drunken Goldfish and Other Irrelevant Scientific Research, Sterling Publishing Co, Inc., New York (1988).
6. F.Balibar, The Science of Crystals, McGraw-Hill, New York, (1993).
7. P.Gross and N.Levitt, Higher Superstition, The Johns Hopkins Academic Press, Boston (1994).

PARAMETER SELECTION IN AUTOMATIC GAS METAL ARC WELDING

Alessandro Rengan

Mahmoud Abdallah

and

John Mingus

Central State University
Manufacturing Engineering Department
1400 Brush Row Road
Wilberforce, Ohio 45384

Telephone: 937-376-6429
e-mail arengan@csu.ces.edu

Biography:

Dr. Alessandro Rengan obtained his B.S. degree in Metallurgy from the Indian Institute of Technology, Madras, India in 1974. He earned his M.S. degree in Materials Engineering from the University of Dayton in 1977 and completed a Ph. D. in Materials Science and Engineering from North Carolina State University in 1992. His major research interests are in the area of ultra hard coatings. He is currently an associate professor at Central State University, Wilberforce, OH, USA.

Dr. Mahmoud Abdallah obtained his B.S. degree in Electrical Engineering from Ain Shams University, Cairo, Egypt. In 1974. He earned his M. S. degree in Electrical Engineering from the University of Rochester in NY in 1981 and completed his Ph. D. in Electrical Engineering from the University of Toledo in 1986. He is currently a full professor at Central State University, Wilberforce, OH, USA.

John Mingus obtained his B.S. degree in Mechanical and Materials Engineering from Wright State University in 1994. He is currently a technician at Central State University, Wilberforce, OH, USA.

Parameter Selection in Automatic Gas Metal Arc Welding

Alessandro Rengan, Mahmoud Abdallah and John Mingus
Manufacturing Engineering Dept.
Central State University
Wilberforce, OH 45384

Abstract:

Gas Metal Arc Welding (GMAW) processes are economical and can be used in automatic or semi-automatic equipment. A large number of weld parameters are available for control, however, and inadequately developed welding procedures can result in less than optimal quality welds. The Design of Experiments (DOE) approach is the most efficient method of identifying the key input factors that optimize the response and minimize the cost. The use of DOE will be discussed to evaluate the optimal parameters that control weld quality.

Key Words: Welding, Robotics, Design of Experiments, Parameter Selection

Prerequisite Knowledge: Basic knowledge of welding processes, that is, types of oxy-fuel welding and arc welding techniques. Statistical analysis of laboratory results including some design of experiments.

Objective: To understand the use of design of experiment approach to optimizing the quality of GMAW welds.

Equipment and Materials:

1. Robotic GMAW Welder (preferred).
2. If not, semi-automatic GMAW can suffice.
3. Low carbon or mild steel cut to size.
4. Tensile testing machine.
5. If not, less accurate results can be obtained with a hardness tester.
6. Grinding wheel.

Safety Precautions:

1. Helmet mask is required.
2. Leather apron and gloves.
3. Use of a welding curtain if bystanders are present.
4. Eye safety goggle is required when using tensile testing equipment.
5. Normal care must be taken to avoid electrical shock when handling the welding equipment.
6. Fumes from the welding operation must be adequately vented.

Introduction:

A major manufacturing process in operation today is welding. Of the many types of welding techniques available, the gas-metal arc welding (GMAW) – or MIG welding process is most amenable for robotic applications. This is due to their simple torch design, good deposition rates and tolerance to joint fit up. Robotic welding offers many advantages such as repeatability, high productivity and good quality. However, due to the large number of control variables involved many welding operators do not thoroughly understand how to optimize arc weld quality. Thereby the speed and maneuverability of the robotic system is not efficiently utilized. The resulting inadequately developed welding procedures have high defect rates, and poor quality in regard to satisfying the requirements of the final product once it is in service.

The technician must determine several primary-welding parameters. These include current, voltage, wire feed speed, travel speed, torch angle and position, shielding-gas flow rates, and electrode extension.

A typical GMAW welding station contains a power supply that delivers an operator set constant voltage, a wire feeder that feeds the filler wire from a coil to a welding gun, and controls for setting welding parameters such as voltage, wire feed and travel speed, and electrode extension. The welding current is proportional to the wire feed speed to maintain a constant melting rate. A power supply applies the necessary current.

Selection of the welding voltage must take into consideration the wires alloy type, wire diameter, type of shielding gas being used, electrode extension, and current. Welding voltage, once set, controls the length of the welding arc, or the distance between the tip of the electrode and the work piece. Adjusting the wire feed speed will control the actual current level. The gun, or welding torch, supplies the welding electrode and shielding gas. The robot controls the welding gun travel speed and positioning.

To optimize the quality of the weld a design of experiments approach was utilized. For the statistical analysis a choice of response or dependent variable was the tensile strength of the weld bead. Next the factors to be varied was selected, the primary weld parameters are voltage, V, wire feed rate, W, and travel speed, T. The choices of two levels of these factors were quantitatively estimated from discussions with people in the field, and from the literature. Due to the expected variation of the results five observations were to be taken at each level and the order of experimentation was to be randomized. This is a 2^3 factorial experiment, the mathematical model for this experiment and design would be:

$$Y_{ijkm} = \mu + T_i + W_j + V_k + TW_{ij} + TV_{ik} + WV_{jk} + TWV_{ijk} + \varepsilon_{m(ijk)}$$

Where Y_{ijkm} represents the measured variable, tensile strength, μ, the true mean of the population, T_i the travel speed effect, W_j the wire feed rate effect, and V_k the voltage effect. Also $i = j = k = 1,2$. $\varepsilon_{m(ijk)}$ represents the random error in the experiment where $m = 1,2,3,4,5$. The other terms stand for interactions between the main factors, T, W, and V.

The hypothesis to be tested was that there was no type of travel speed effect, no wire feed effect, no voltage effect, and no interactions.

Experimental:

An Automatix robot system was used with a AI32 controller. For the welding application a welding gun could be fixed to the robotic arm. When the system is equipped with welding equipment and software it is called Robovision II-600. The operator can use the Integrated Command Module (ICM) to include WELD statements into the program created from the ICM. The WELD commands direct the robot to move along a path with the welding arc turned on. The welding parameters (travel speed, wire feed rate and voltage, etc) for each weld, are contained in tables referenced as "weld schedules". Selecting different schedules may change these parameters. Once the Robovision II-600 is in place, the AI32 controller overrides the setting on the welder. Every command is therefore remotely controlled.

The shielding gas used for the GMAW purpose was 100 % CO_2 gas. A butt joint assembly made out of 1/8" thick low carbon steel (type 1120) bar was used to make test welds on two 3" long pieces. The electrode was 0.030" diameter ER 70S-6. A constant voltage power supply was used in reverse polarity. The travel speeds of 6 and 12 in./min were selected. Wire feed rate of 150 and 180 in./min were chosen. And voltages of 23 and 28 V were used. Tensile testing was done on a SATEC 60 UTS machine.

Results:

The analysis of this experiment consisted of collecting 40 items of data in a randomized manner. The results in pounds of tensile load to fracture the samples are given in Table I.

Table I

Tensile Load necessary to fracture welded specimens in pounds.

Travel Speed	Wire Feed	Voltage	
		23 V	28 V
6 in/min	150 in/min	1933 lbs	3800 Lbs
		1933	2066
		3600	1434
		1145	1561
		2200	1666
	180 in/min	4066	3066
		3200	4922
		3866	4866
		3800	4546

		2866	4934
12 in/min	150 in/min	1533	2066
		1466	2733
		3733	3466
		1066	2933
		2476	2866
	180 in/min	8000	4933
		3066	4866
		4500	3466
		3066	4000
		2666	5066

This experiment and the mathematical model suggest a three-way analysis of variance (ANOVA) which yields the results in Table 2.

Table 2
ANOVA for Tensile Breaking Load of Welded Specimens

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Travel Speed *T*	1	105.6	105.6
Wire Feed *W*	1	3626.2	3626.2 *
Voltage *V*	1	205.9	205.9
T x W interaction	1	0.6	0.6
T x V interaction	1	0.8	0.8
W x V interaction	1	10.6	10.6
T x W x V interaction	1	144.1	144.1
Error ε	32	10791	337.2
Totals	39	14885	

At the 5-percent significance level ($\alpha = 0.05$), the critical region of 'F' is F > 4.15. Comparing each mean square with the error mean square indicates that only **one hypothesis** can be rejected: *Wire Feed Rate has no effect on the tensile breaking load.* None of the other hypothesis can be rejected and it is concluded that only the Wire Feed Rate (indicated by an asterisk) affects the tensile breaking load. Travel Speed and Voltage appears to have little effect on the tensile breaking load, and all interactions are negligible. Calculations on the original data of Table 1 show the average tensile breaking loads given in Table 3.

Table 3
Average Tensile Breaking Loads of Welded Specimens

Parameter	Value	Avg. Tensile Load
Travel Speed *T*	6 in/min	3073 Lbs
	12 in/min	3400
Wire Feed *W*	150 in/min	2283
	180 in/min	4190
Voltage *V*	23 V	3008
	28 V	3462

These averages seem to bear out the conclusion that Wire Feed Rate affects the tensile breaking load with the 180 in/min requiring a higher tensile load than the 150 in/min wire feed rate.

Graphing all four 'wire feed rate' and 'voltage' combinations in Figure 1 shows the meaning of no significant interactions.

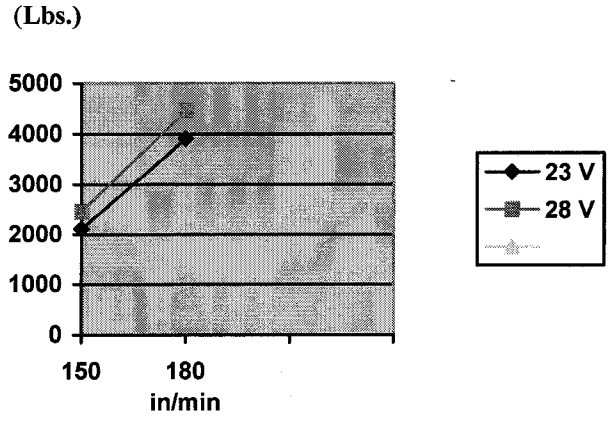


Figure 1. Tensile Breaking Load Vs. Wire feed rate and Voltage interaction.

A brief examination of this graph indicates that the tensile breaking strength is increased by an increase in the wire feed rate. The fact that the line for the 28 V is above the line for the 23 volts shows that the 28 V weld implies a slightly higher tensile breaking load. The fact that the lines are nearly parallel is characteristic of no interaction between two factors. Or, it can easily be seen that an increase in the wire feed rate produced about the same average increase in the tensile breaking load regardless of which voltage was used. This is another way to interpret the presence of no interaction.

Conclusion:

1. Automatic GMAW has numerous parameters that can be varied to give welds with different tensile breaking loads.
2. A three-factor experiment with two levels was designed and the data was analyzed by a three-way ANOVA with five observations per cell.
3. From the results it was shown that only one factor (wire feed rate) affected the tensile breaking load.
4. It was also determined that within the range of the experiment it makes little difference which voltage and travel speed are used, and that there are no significant interactions between the three factors.

References:

1. Fundamental Concepts in the Design of Experiments. Charles R. Hicks, Third Edition. Pub: Holt, Rinehart and Winston, Inc. 1984.
2. "Weld Parameter Development for Robot Welding" Dennis D. Harwig, Robotics Today, 10, 1 (1997) 1-7.

Acknowledgements:

The authors would like to acknowledge the efforts of three seniors who worked on this project for their senior design. They are Ibrahim Cisse, Oumar Diallo and Victorien Ndounou.

LAB MANUAL & RESOURCES FOR MATERIALS SCIENCE, ENGINEERING AND TECHNOLOGY ON CD-ROM

James A. Jacobs

and

Alfred E. McKenney

Department of Technology
Norfolk State University
700 Park Avenue
Norfolk, Virginia 23504-8060

Telephone: 757-823-8109
e-mail jajacobs@nsu.edu
aem2@prodigy.net

Alfred E. McKenney

LAB MANUAL & RESOURCES for MATERIALS SCIENCE, ENGINEERING AND TECHNOLOGY on CD-ROM

James A. Jacobs and Alfred E. McKenney
School of Science & Technology
Norfolk State University
Norfolk, VA 23504
jajacobs@nsu.edu
NEW:Update Site - http://MST-Online.nsu.edu/new01

Key Words
CD-ROM, materials, experiments, papers, NEW:Update, workshop, structure, testing, evaluation, metals, polymers, ceramics, composites, electronic, optical, curriculum

Prerequisite Knowledge: Familiarity with Adobe Acrobat Reader. (See the *Getting Started* section, at the end of this paper.)

Objective: To assess experiments, demonstrations and other resources on the *EMSET2* CD-ROM for adaptation to classroom and laboratory instruction related to materials science, engineering and technology.

Equipment: Windows: Microsoft Windows 95 or higher, Windows NT with Service Pack 3 or later. Apple: Power Macintosh, Apple System Software v7.1.2 or later. UNIX: Solaris 2.3 (both SPARC and Intel processors), HP-UX 9.05, IRIX 5.3, OSF/1 4.0, AIX 4.1.

Acrobat Reader v4 with search and QuickTime v4.

Abstract
The National Educators' Workshop (NEW:Update) series of workshops has been in existence since 1986. These annual workshops focus on technical updates and laboratory experiments for materials science, engineering and technology, involving new and traditional content in the field. Scores of educators and industrial and national laboratory personnel have contributed many useful experiments and demonstrations which were then published as NASA Conference Proceedings. This "out poring of riches" creates an ever-expanding shelf of valuable teaching tools for college, university, community college and advanced high school instruction. Now, more than 400 experiments and demonstrations, representing the first thirteen years of NEW:Updates have been selected and published on a CD-ROM, through the collaboration of this national network of materials educators, engineers, and scientists. The CD-ROM utilizes the popular Adobe Acrobat Reader format and operates on most popular computer platforms.

This presentation provides an overview of the second edition of *Experiments in Materials Science, Engineering and Technology* (*EMSET2)* CD-ROM, ISBN 0-13-030534-0.

Background - Annual NEW:Updates & Publications

The National Educators' Workshop (NEW:Update) series of workshops has been in existence since 1986. NEW:Updates focus is on strengthening materials education through technical updates and publication of laboratory experiments and demonstrations for materials science, engineering and technology, involving new and traditional content in the field.

The National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), National Institute of Standards and Technology (NIST), and Norfolk State University (NSU), have provided the major funding for these workshops. Joining in support are the American Society for Engineering Education, ASM International, American Society for Testing & Materials, Battelle Pacific Northwest Laboratory, Boeing Airplane Company, Ford Motor Company, Martin Marietta Energy Systems, Inc, The International Council for Materials Education, Oak Ridge National Laboratory, DaimlerChrysler, General Motors and Gateway Coalition.

Workshop participants witness presentation of experiments and demonstrations, developed by faculty, scientists, and engineers throughout the United States. They discuss issues of MSE (materials science and engineering) with people from education, industry, government, and technical societies, and hear about new MSE developments. Half-day mini workshops in small groups are conducted in state-of-the-art laboratories at the host laboratories including NASA Langley Research Center, National Institute of Standards and Technology, Oak Ridge National Laboratory, Los Alamos National Laboratory, Boeing Airplane Company-Seattle, Columbia University/Brookhaven National Laboratory, University of Michigan/DaimlerChrysler.

An extensive peer review process of experiments is followed. After submission of abstracts, selected authors are notified of their acceptance and given the format for submission of experiments. Experiments are reviewed by an international panel through the cooperation of the International Council for Materials Education. Authors receive comments from the panel prior to workshops allowing them to make necessary adjustments to their experiments. Participants who attend NEW:Updates, observe demonstrations of the experiments and provide critiques for the authors to make further modifications prior to this publication. Final editing has been done by the publication staff of the National Aeronautics and Space Administration.

The CD-ROM Compendium

After several years of NEW:Update Workshops and the popularity of the experiments resulting from the meetings, the organizing committee, with assistance from the Materials Division of ASEE, began work on a compendium of selected experiments. Support for this collection came from a broad range of individuals, agencies, and technical societies, much like the support for the NEW:Updates Workshops themselves.

The original idea aimed to produce hard copies of about 50 selected experiments. However, at NEW:Update 94, Alfred and Evelyn McKenney and Robert Berrettini presented a concept by which all experiments could be placed on a CD-ROM in a format that would provide materials educators an easy way to find and use any of the experiments. Additionally, instructors could

customize the experiments to meet their students'needs. After further research on methodology and efforts to secure funding, we were able to put together a project that used several sources of funds, much volunteer help and resources, and a publisher who would produce and package the *EMSET* CD-ROMs from the master and distribute them.

The structure of *EMSET* allows materials educators to manipulate individual papers in a variety of ways for either hard copy or digital output. They can edit their selection to fit their own environment and to suit their students' needs. The first edition of *EMSET*, containing papers from the first decade of the Workshops, was released in 1997. This second edition, *EMSET2*, containing an additional three years of papers and expanded teaching content, was published in the fall of 2000.

EMSET2 Content

The EMSET2 CD-ROM contains three major sections as shown on the Main Menu in Fig 1.

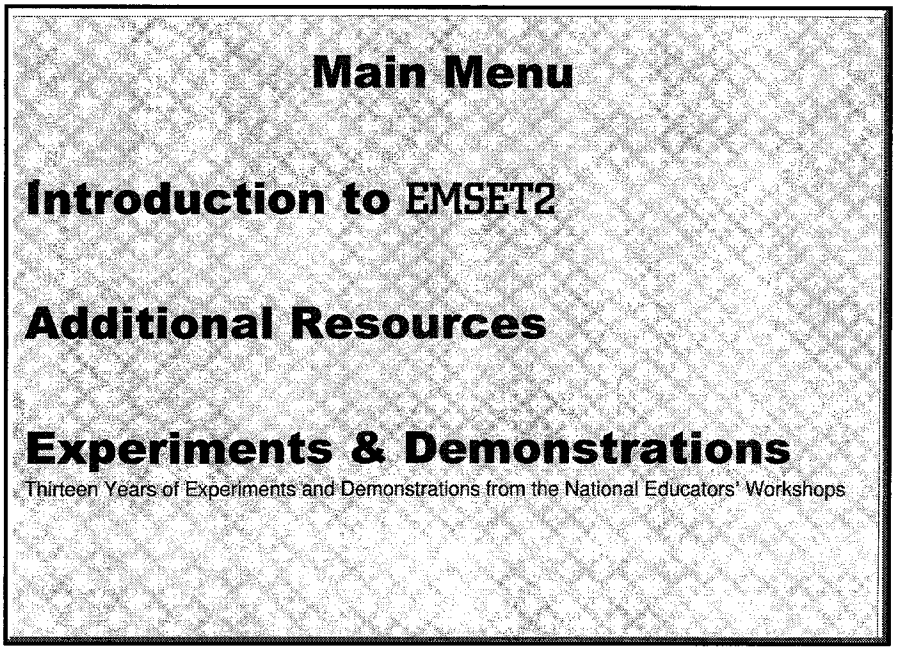


Fig 1 - Main Menu

The INTRODUCTION TO EMSET2 section contains further information about EMSET2's content, contributors and provides help in getting started.

The ADDITIONAL RESOURCES section contains supplemental teaching material. Examples are shown below.

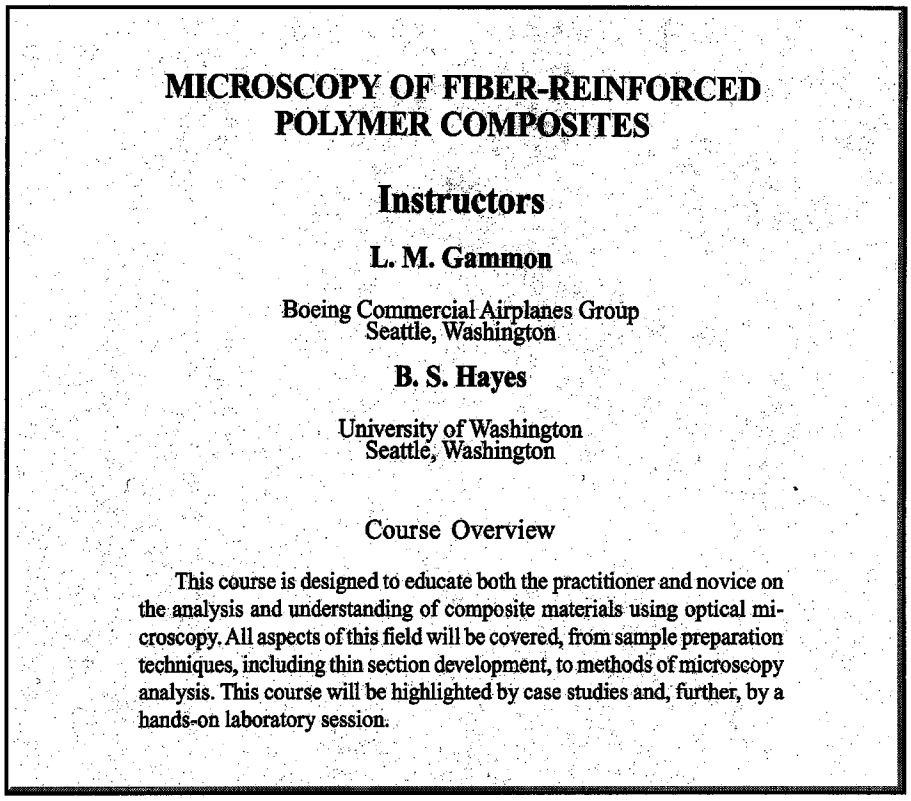
The EXPERIMENTS & DEMONSTRATIONS section contains over 400 demonstrations and experiments. It is the heart of the NEW:Update workshops and the EMSET2 CD-ROM and is further described below.

While it is difficult to demonstrate the richness of the teaching resources contained in EMSET2, in a brief space, we will present some description and examples of its content over the next few pages.

The Additional Resources Section

This section contains a wide range of material aimed at providing instructors with additional resources to supplement their classroom curriculum. This material ranges from a short course on microscopy for advanced composite materials, an extensive listing of relevant web sites, through applications of materials, photos, photomicrographs, structures and models.

There are examples on this page and the next:



MICROSCOPY OF FIBER-REINFORCED POLYMER COMPOSITES

Instructors

L. M. Gammon

Boeing Commercial Airplanes Group
Seattle, Washington

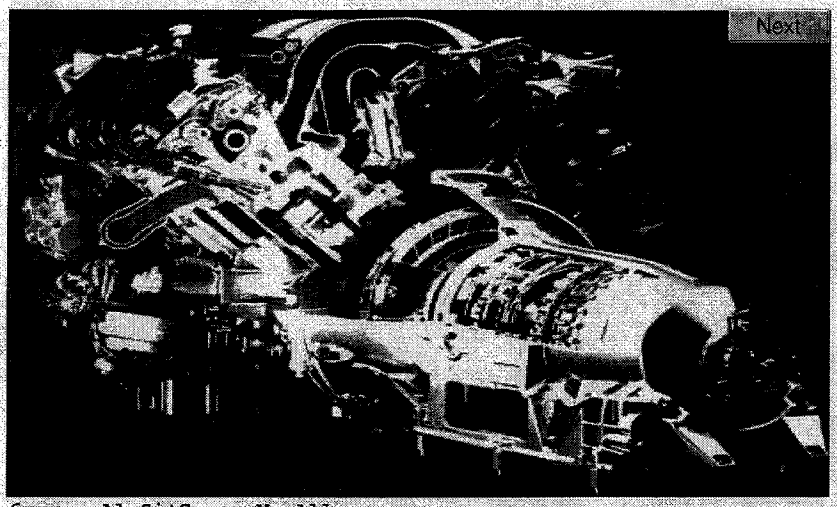
B. S. Hayes

University of Washington
Seattle, Washington

Course Overview

This course is designed to educate both the practitioner and novice on the analysis and understanding of composite materials using optical microscopy. All aspects of this field will be covered, from sample preparation techniques, including thin section development, to methods of microscopy analysis. This course will be highlighted by case studies and, further, by a hands-on laboratory session.

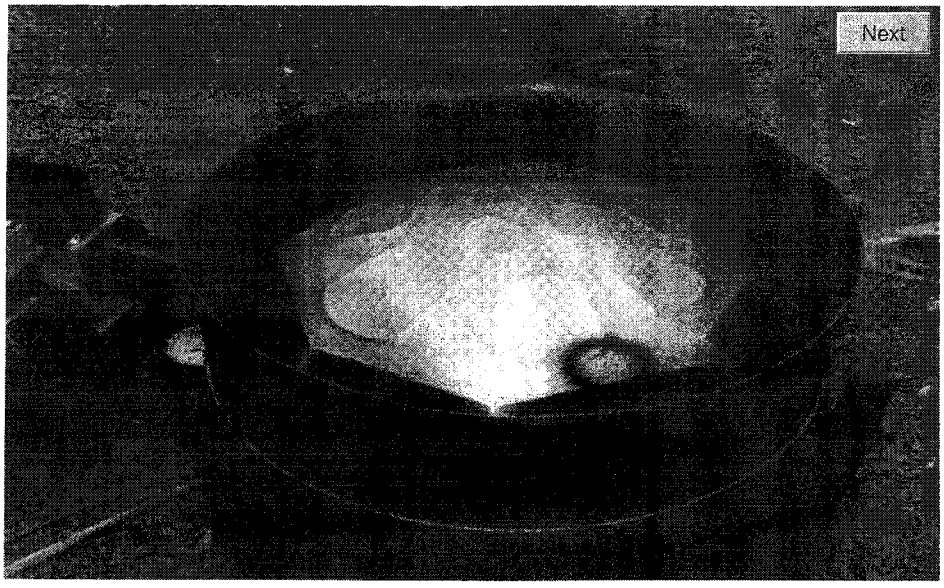
Fig 2 - A Short Course on Microscopy of Fiber-Reinforced Polymer Composites



6xxx - Al-Si+Cu or Mg Alloys

* Heat treatable/sand, permanent mold, and die castings
* Excellent fluidity/high strength/some high-toughness alloys
* Automotive and applications/pistons/pumps/electrical
* Representative alloys: 356.0, A356.0, A359.0, A360.0
* Approximate ultimate tensile strength range: 19-40 ksi

Fig 3 - Application of Materials in the Automotive Industry



Color changes guide the heat treatment of a drum. In this example, a kerosene fired heat source produced a flame of approximately 600 degrees Celsius. The maker placed a drum upside-down over the heat. Lawrence E. Murr and Everaldo Ferreyra Tello, *Pandemonium* Steel Drum Ensemble. "Connecting Materials Science and Music in Steel Drums" *American Scientist, January, 2000.*

Fig 4 - Application of Materials in the Field of Art

Experiments & Demonstrations Section

This section includes over 400 experiments and demonstrations in PDF format from the annual NEW:Update workshops. They have been reproduced in their original peer-reviewed form, preserving the individuality among the papers and reflecting the author's style and method.

The TABLE OF CONTENTS classifies the papers into seven categories: Structure, Testing & Evaluation, Metals, Polymers, Ceramics, Composites, Electronic & Optical Materials and Materials Curriculum.

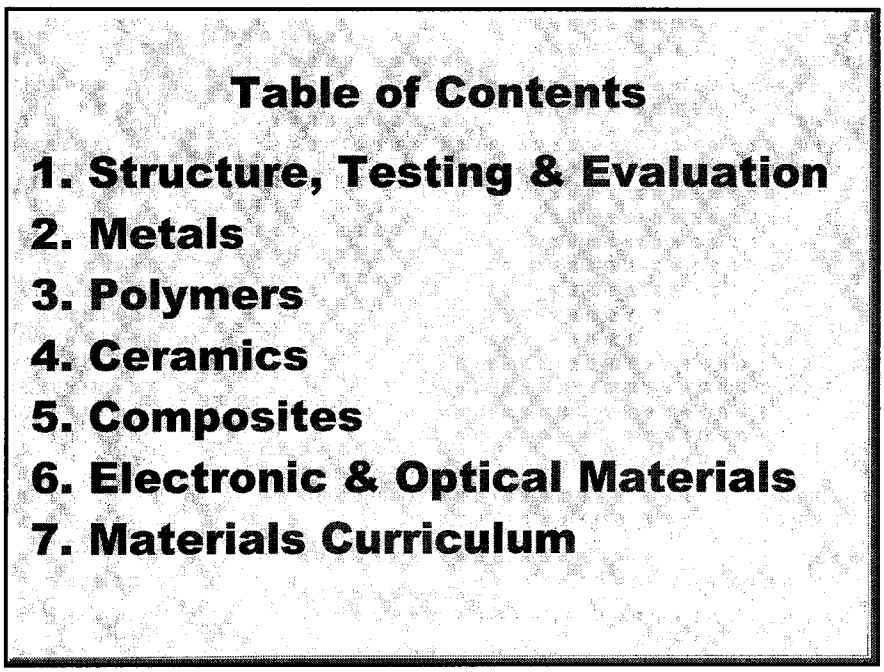


Fig 5 - Table of Contents

To find the document(s) meeting your needs, the user can:

- Browse the Table of Contents which is organized by types of materials or processes, or
- Use the full Text Search capability, searching by:
  - Author
  - Title
  - Subject
  - Text words in context

The PDFs are indexed for full text search when using the ADOBE™ ACROBAT READER WITH SEARCH program. The "word stemming" and "sounds like" features are enabled to allow the greatest freedom in locating the content desired.

While the detailed Table of Contents can also be scanned to find the material desired, the user will probably use the Full Text Search more often because the subject matter of papers sometimes fits into more than one category.

Once located, the ACROBAT READER gives the user the ability to:

- View an exact image of the original paper,
- Read, or print the paper, or copy its text into another document for editing.

The following page demonstrates the power of the "word stemming" capability. The search word "hardness" finds such occurrences as "harden," and "hardening."

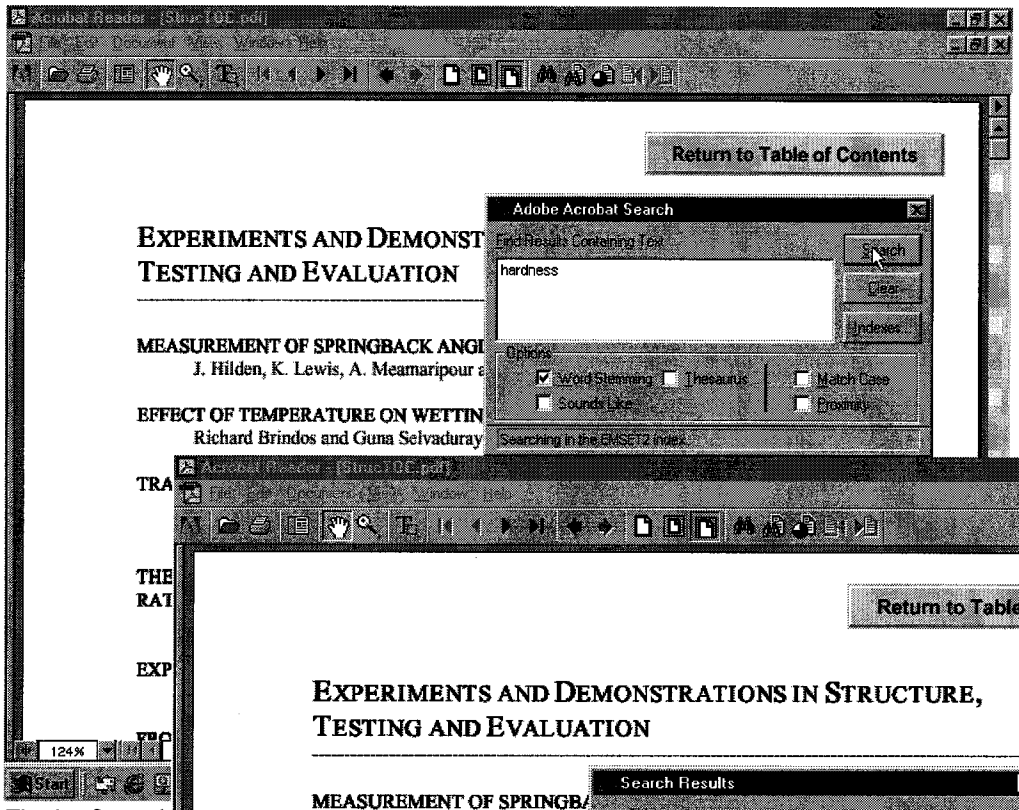


Fig 6 - Search

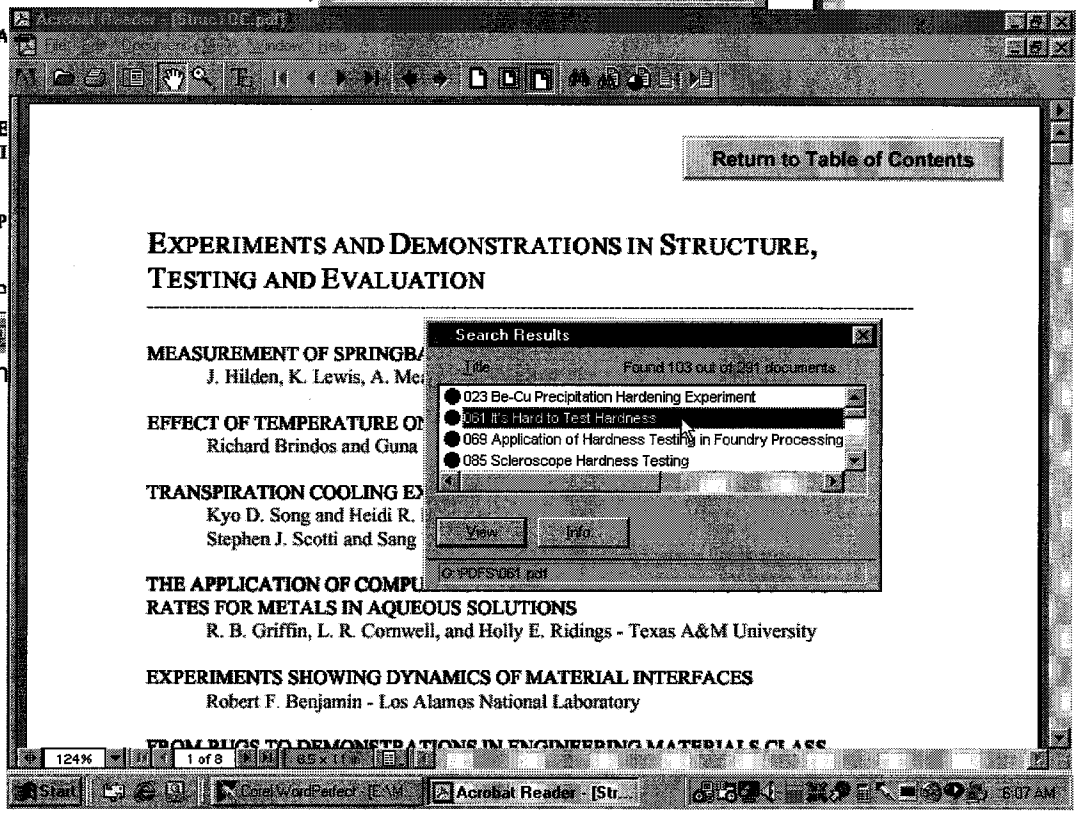


Fig 7 - Showing some of the Full Text Search results for "hardness," using Word Stemming

Selection of the first page of the highlighted paper is shown on the next page.

Using the Papers

In many cases, you will probably use the experiments as they were published.

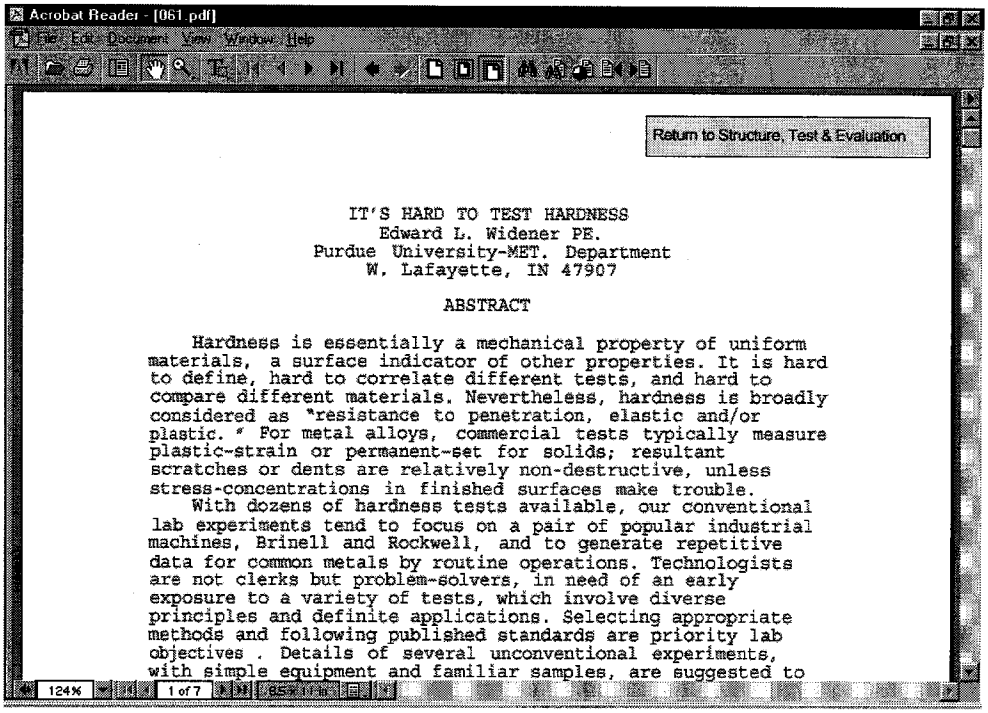


Fig 8 - A Selected Paper on "Hardness;" Ed Widener's

However, you may sometimes wish to edit a paper for a particular need, even combining it with other papers. You can use the Acrobat Exchange program. However, if you do not have access to this program, there are two other methods of editing to chose from:

- Print the paper, then cut and paste as needed. You all know how to do this. - or,
- Copy blocks of text and graphics to the clipboard, then paste into a word processor or graphics program.

When all of the material desired has been copied into the word processor, the instructor can create additional material to suit the specific needs of his or her class. Here is an example of a data sheet which could accompany the paper on "hardness."

TMD145

Brinell Hardness Test Data Sheet

Student Name _____ Date _____

Sample #	Material Description	Load (Kg)	Dent Dia (mm)	BHN
1				
2				
3				
4				
5				

Fig 9 - A Locally-created Student Data Sheet

Acknowledgments and Fair Use

This CD-ROM resulted from scores of people contributing experiments and demonstrations to the annual National Educators Workshop:Updates in Engineering Materials, Science, and Technology (NEW:Updates). Their names are listed with their experiments on the CD-ROM, as are the many other people and agencies who helped in this project. Cooperative funding among

private industry, academia, and NASA allowed for production of the CD-ROM master, with the understanding that production and distribution would be done by a publisher. Prentice-Hall, Inc. agreed to become the publisher.

EMSET2 is licensed for departmental use. Faculty have the right to cut and paste papers from the CD-ROM to suit their needs. However, users should give credit to the original authors.

Getting Started

Finally, to assist in finding your way around *EMSET2*, you may wish to print out the *Getting Started* section to use as a reference. To do this, select the GETTING STARTED button from the Introduction Menu. After *Getting Started* appears, select and execute PRINT from the File Menu.

Bios

James A Jacobs

James A Jacobs is Professor of Engineering Technology at Norfolk State University. He developed the concept and has been co-director of all the NEW:Updates. He has thirty-three years of teaching experiences in public schools, community colleges, and universities. He has developed curricula offerings at all three levels, including courses in material science, materials and processes technology, engineering materials technology, and principles of manufacture.

He has industrial experience with Westinghouse Corp., Tenneco, Ford Motor Co., and completed an intensive ten-week program with International Business Machines Manufacturing Technology Institute.

He is the author of numerous articles, books, and technical papers and presentations. Dr. Jacobs co-authored Engineering Materials Technology, now in its third edition, and the CD-ROM set, Experiments in Materials Science, Engineering and Technology both published by Prentice-Hall Inc. He has been involved as consultant and director with numerous grants, seminars, and curriculum development efforts in engineering materials, manufacturing, robotics and CAD/CAM.

Professor Jacobs is a member of the Materials Education Council of the United States, ASM International, Society of Manufacturing Engineers, American Society for Engineering Education, American Association of University Professors, American Ceramics Society, and is a Certified Senior Technologist and member of the National Association for Industrial Technology.

Alfred E McKenney

Alfred E McKenney received his BS in engineering from the US Coast Guard Academy at New London, Connecticut. After service as a line officer, he earned his MBA at Harvard Business School. He was employed by IBM for 37 years where he specialized in the design of large manufacturing planning and control systems.

In 1987, he was assigned by IBM on a two-year sabbatical to the School of Technology at Norfolk State University where he taught courses in computing, tool design, mechanics, engineering material technology, robotics, CIM, and production planning and inventory control. On retiring from IBM, he continued teaching for two more years at Norfolk State, as well as working with Dr. Jacobs on NEW:Update. He is now enjoying retirement and occasional independent consulting with his wife, Evelyn.

End

Click on ,Http://MST-Online.nsu.edu> and

Link to the cool

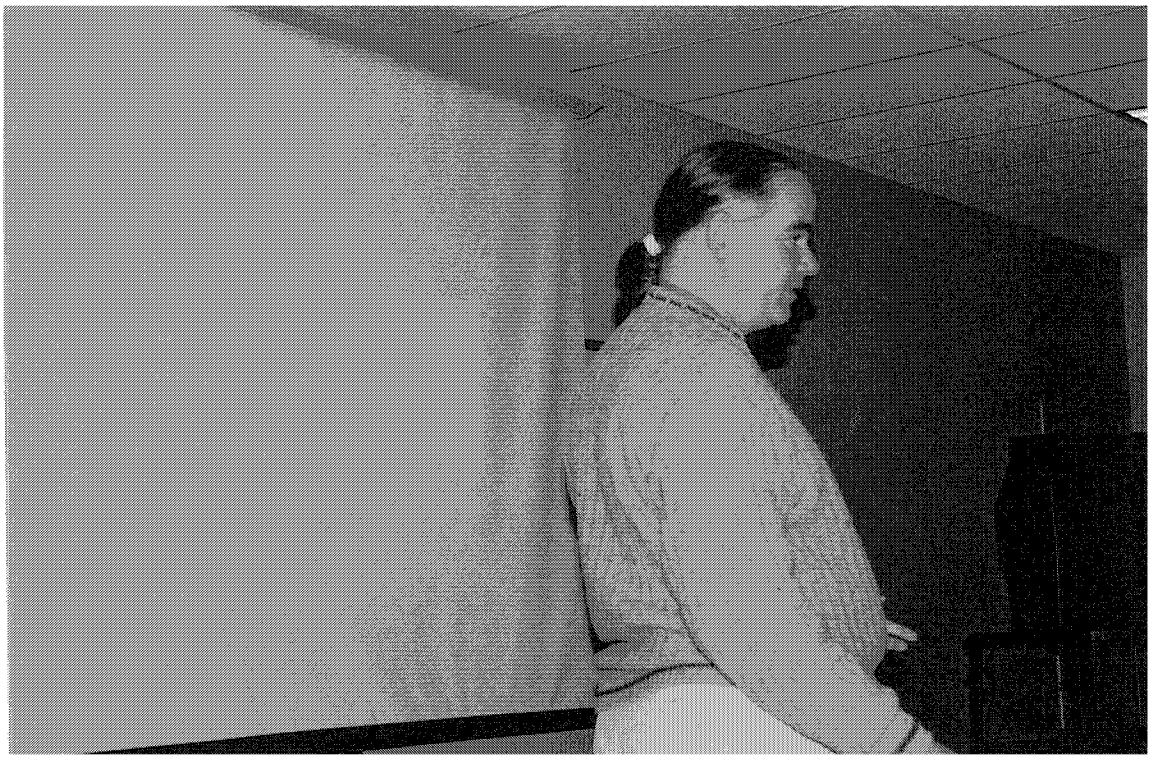
World of Materials, Science, & Technology

THE Bi-Sn EQUILIBRIUM PHASE DIAGRAM

Mike Meier

Department of Chemical Engineering and Materials Science
University of California, Davis
Davis, California 95616

Telephone: 530-752-5166
e-mail mlmeier@ucdavis.edu



Mike Meier

THE BI-SN EQUILIBRIUM PHASE DIAGRAM

Mike Meier
Department of Chemical Engineering and Materials Science
University of California, Davis
Davis, CA 95616
USA

Key Words: equilibrium phase diagram, eutectic, thermocouple

Prerequisite Knowledge: basic understanding of equilibrium phase diagrams, eutectic reactions, and temperature measurement using thermocouples.

Objective: In this experiment the cooling curve method is employed to determine the transformation temperatures for a series of Bi/Sn samples. These results are then used to construct an equilibrium phase diagram and this phase diagram is then used to determine the composition of a sample whose composition is unknown. This experiment also provides an introduction to digital data acquisition, temperature measurement using thermocouples, and the use of spreadsheets in analyzing experimental data.

Equipment and Materials: The following is a list of the types equipment that may be used in this experiment. Please make sure you have everything you need before starting the experiment and note exactly what type of equipment you will be using.

1. A heater capable of heating the test tubes to 400°C
2. Test tubes to hold the samples
3. Tongs for handling the hot test tubes
4. Electronic balance with 0.01 gram sensitivity
5. Weigh boats and two spoons
6. Insulated beakers (600 ml beakers filled with glass or ceramic wool)
7. Thermocouples with extension wires and reference junctions
8. DMM/scanner connected to a computer or another type of data acquisition system capable of measuring temperature using thermocouples
9. Containers for disposing of the samples and the test tubes
10. Pure metals which are in either a granular or shot form. Note the type of metals used, their manufacturers, purities, form and part numbers

Introduction: Equilibrium phase diagrams are one of the single most useful tools of a materials scientist and engineer. As maps of the temperature ranges and solubility limits of each known phase in the alloy system, including compounds, they are obviously useful to metal casters, heat treaters and ceramicists and are an invaluable tool in alloy design, in the development of high-temperature superconductors and in investigations of practically any temperature-dependent property. To one who is familiar with how these diagrams are generated and especially to those who calculate phase diagrams they are also representations of a number basic thermodynamic properties and in themselves contribute to a better understanding of engineering materials.

There are a number of methods available for establishing a phase diagram. One, high-temperature x-ray diffraction, allows one to make direct measurements of the changes in structure at temperature, allowing one to study the details of the crystallographic aspects of phase transformations. Electron diffraction, done using a transmission electron microscope, can be used to obtain similar results but at very high magnifications, allowing one to locate and identify very small precipitates of the new phase. But the most commonly used methods are based on thermal analysis. These include differential scanning calorimetry (DSC) which measures the heat energy expelled or adsorbed by the sample as it undergoes phase transformations and differential thermal analysis (DTA) which carefully measures changes in heating or cooling behavior as compared to a reference material. Both of these can also be used to measure fundamental thermodynamic quantities such as heat capacity, enthalpy and entropy. Dilatometry is another thermal analysis technique which is widely used to measure the coefficient of thermal expansion but can also determine a transformation temperature by detecting the sudden change in volume due to the density change associated with a phase transformation. In general, one can devise any number of bulk and microanalysis-based methods for establishing a phase diagram by measuring any change in the sample which accompanies a phase transformation. In practice, the results of a number of techniques published by many authors are collected and carefully evaluated by the scientific community before they are made available for more general use and even then you may find differences in phase diagrams for the same system (compare the phase diagrams in references 1 and 2).

The Bi-Sn system is a classic binary eutectic system and is a good example of a system which exhibits limited solid solubility and no intermediate compounds. Its phase diagram is very similar to that of the well known Pb-Sn system which provides us with a number of solders, including the 40-60 solder which is widely used in electrical applications. The simplicity of this type of system combined with the lower melting temperatures and lower toxicity of the Bi-Sn system makes it an ideal candidate for classroom experiments. As a low melting alloy Bi-Sn alloys are used in temperature overload devices and as solders in cases where the Pb-Sn solders are not suitable. For example, they may be used in wave soldering operations where surface mount components make direct contact with the molten metal, when the heat treatment of the metals being joined can be altered, when soldering other low melting point alloys such as pewter and when nearby solder joints might be compromised [3].

Procedure:

Preparation: Before actually starting the experiment stop to consider the suitability and performance of the instrumentation, certain aspects of the experimental procedure and to try to anticipate the experimental results. This will help ensure that the experiment goes well the first time. The following questions should get you started.

1. Sketch the equilibrium phase diagram for the Bi-Sn system. Label all phase fields and distinctive features.

2. What are the highest and lowest transformation temperatures you expect to measure when working with the 0, 10, 30, 50 and 100 weight percent Sn samples?

3. Estimate the value of Seebeck's coefficient for the type of thermocouple you will be using and for temperatures between room temperature and 300°C?

4. Combining questions 2 and 3, what are the lowest and highest voltages you will be measuring? What voltage resolution will you need to be able to resolve 1 °C? What is the voltage resolution of your system?

5. When you put the thermocouple into the molten Bi/Sn mixture the thermocouple will cause the liquid to cool, possibly solidifying some of it before you can start measuring its cooling behavior. How do you plan to deal with this?

6. If your thermocouple reference junction is not turned on or if the battery is dead, how much error would you expect to see in your temperature measurements?

7. Assuming you have done everything perfectly and the thermocouple is your only source of error, how large might this temperature error be?

8. If you don't weigh out your Bi and Sn perfectly you can expect the transformation temperatures you measure to differ from those in the established phase diagrams. How much error in weighing do you expect to see and how do you plan to deal with this error?

9. Indicate on your sketch (question 1) the sample compositions and transformation temperatures which will not be effected by errors in weighing out the Bi and Sn for your samples?

10. Assume your "unknown" sample has transformation temperatures of 139 and 195 °C. Referring to your equilibrium phase diagram you can see that this fits two compositions. How would you figure out which composition it is?

Safety This experiment presents minor hazards for all students in the laboratory. Test tubes occasionally break so safety glasses should be worn from the moment the first specimen is heated until the last one is cool. The specimen materials themselves pose minor hazards due to their toxicity. These should be handled carefully and disposed of properly. (MSDS's for each chemical are available in the laboratory.) The most serious hazard is the possibility of being burned by the heater and the hot test tubes. The ceramic tubes that hold the test tubes are heated to nearly 400 °C and the test tubes are often heated to above 300 °C.

Chemical Hazards	There are hazards associated with the minor toxicity of Sn and Bi. These materials should not be ingested and proper disposal methods should be used. Refer to the MSDS for each material.
Physical Hazards	Serious burns are possible. The ceramic heater tubes and the specimens in the test tubes are heated close to 400 °C. The hot parts of the heater are labeled accordingly. Test tube clamps should be used when handling the hot specimens. The glass test tubes often break and spill the molten metal, especially when being reheated to remove the thermocouple. Safety glasses and closed toe shoes must be worn at all times.

Biohazards	None.
Radiation Hazards	None.
Protective Equipment	Recommended: laboratory aprons and long pants. Required: safety glasses or goggles. Normal eye-glasses are not acceptable. Open toed shoes will not be allowed.

Procedure Examine the setup of the experimental equipment. Find out what each part does and how each part works. Make sure everything is working properly and if possible try a couple of dry runs of the experiment.

Weigh and mix the pure components to make samples of the specified compositions and the specified total weight. Transfer the pure components to a test tube and then cover and shake the test tube to thoroughly mix them. Finally, label each sample immediately to avoid mixing them up. Note that it might not be possible to weigh out these granular materials as precisely as you'd like so make sure you record the actual composition of each sample.

Prepare the data acquisition system in advance. It should be ready to start collecting data as soon as the samples are transferred to the beakers and the thermocouples are plugged in. If you have time you can run it in demo-mode to learn more about what the program can do while you colleagues are preparing the samples.

Carefully and gently melt each sample. Be careful to not overheat them or to heat them for too long as you might oxidize the sample or damage the test tube. On the other hand, make sure the sample has completely melted before removing it from the heater and while you don't want to overheat the sample you should heat it high enough above its liquidus that is doesn't start to solidify before you can start recording the cooling behavior.

Transfer the test tubes containing the melted samples to the insulated beakers and start recording the cooling behavior as soon as possible. Continue recording until you are sure that no additional phase transformations are expected. (Consult an established Bi/Sn phase diagram.) When done remelt the sample so that you can remove the thermocouple. Clean the thermocouple and dispose of the sample properly.

Start the spreadsheet program and load the spreadsheet that has been prepared for this experiment. This spreadsheet will help you quickly construct, display and print cooling curves, cooling rate curves, and to determine the temperature at the start of the phase transformations. Use the "Import" macro (alt-I, or the "Import" Button) to import the data, the "View" macro (alt-V) to view the cooling curve and the "Print" macro (alt-P) to print the cooling curve. Change the scaling of the graph as needed, and view the data on the other pages of the spreadsheet to review the temperature and cooling rate data and to determine the temperature at various points along the cooling curves.

Results A good way to start your analysis of the results is to make a brief qualitative review of the cooling curves. Which features do they all have in common, which ones are unique and what is the

significance of each of these features? Are there different "types" of cooling curves and if so what type is the cooling curve for the "unknown" sample?

Moving on to the quantitative part of this section of the report, you will have to devise the best method for reliably and consistently determining the transformation temperatures. Perform this analysis, organize these results in a table and then plot these data points on an existing phase diagram. Note the similarities and differences and note the character and the magnitude of the experimental errors.

Once your own phase diagram is complete you should be able to determine the composition of the "unknown" composition which was provided by your instructor. In your report you will have to explain exactly how you did this and how much error you think there might be in your result.

Record any other interesting observations you may have made. These notes can be very helpful when writing your report.

Discussion This experiment is straightforward and is essentially a duplication of the work of others. Your discussion will probably start out comparing your phase diagram to established phase diagrams (see figures 2 and 3) and you may even be able to say which phase diagram you'd put more stock in. Next, you may revisit the issue of experimental error before finally reviewing how the composition of the "unknown" was determined and telling the reader how confident he/she can be that your determination is correct. In general, you will have to convince the reader that you have done a good set of experiments, constructed a good equilibrium phase diagram and have demonstrated its usefulness by determining the composition of the "unknown" sample.

Conclusion Formulate your own conclusions regarding the quality and utility of the phase diagram you have constructed. You may have also made other observations which merit a final comment. This is a good opportunity to make these comments.

References:

1. ASM Metals Handbook, Alloy Phase Diagrams, 10th edition, ASM International, Metals Park, OH, vol.3, p.106, (1992).
2. Eric Brandes, ed., Smithells Metals Reference, 6th edition, Butterworths, London, p11-139 (1983).
3. ASM Metals Handbook, Properties and Selection: Nonferrous and Special-Purpose Materials, 10th edition, ASM International, Metals Park, OH, vol.2, pp.753-757, (1992).

Bibliography:

Michael L. Meier received his B.S. in Materials Engineering from North Carolina State University in 1979 and his M.S. (1986) and Ph.D. (1991) in Materials Science and Engineering from the University of California, Davis. After a two-year post-doctorate position at the Universität Erlangen-Nürnberg in Erlangen, Germany he returned to UC Davis where he is the director of Materials Science Central Facilities and teaches many of the laboratory courses.

Worksheet for the Binary Phase Diagram Experiment

Section_____ Date_____

Lab Partners_____

_____

Equipment

Balance Model_____ Serial Number_____

Voltmeter Model_____ Serial Number_____

Computer Model_____ Serial Number_____

Data Acquisition Software Name_____ Version_____

Characteristics of thermocouples used

Thermocouple Type	Temperature Range, °C	Typical Temperature Error, °C	Reference Junction Type/Model

Raw Materials

Element	Purity %	Melting Point °C	Manufacturer	Product Number

Prepared specimens

Nominal Composition	Element:_____ Weight, g	Element:_____ Weight, g	Total Weight, g	Actual Composition
0/100				
10/90				
20/80				
30/70				
40/60				
50/50				
60/40				
70/30				
80/20				
90/10				
100/0				

Compositions are given in weight percent.

Data acquisition and storage

Compositions in the File	Sampling Rate, Hz	Maximum Temperature, °C	Minimum Temperature, °C	File name (*.prn)

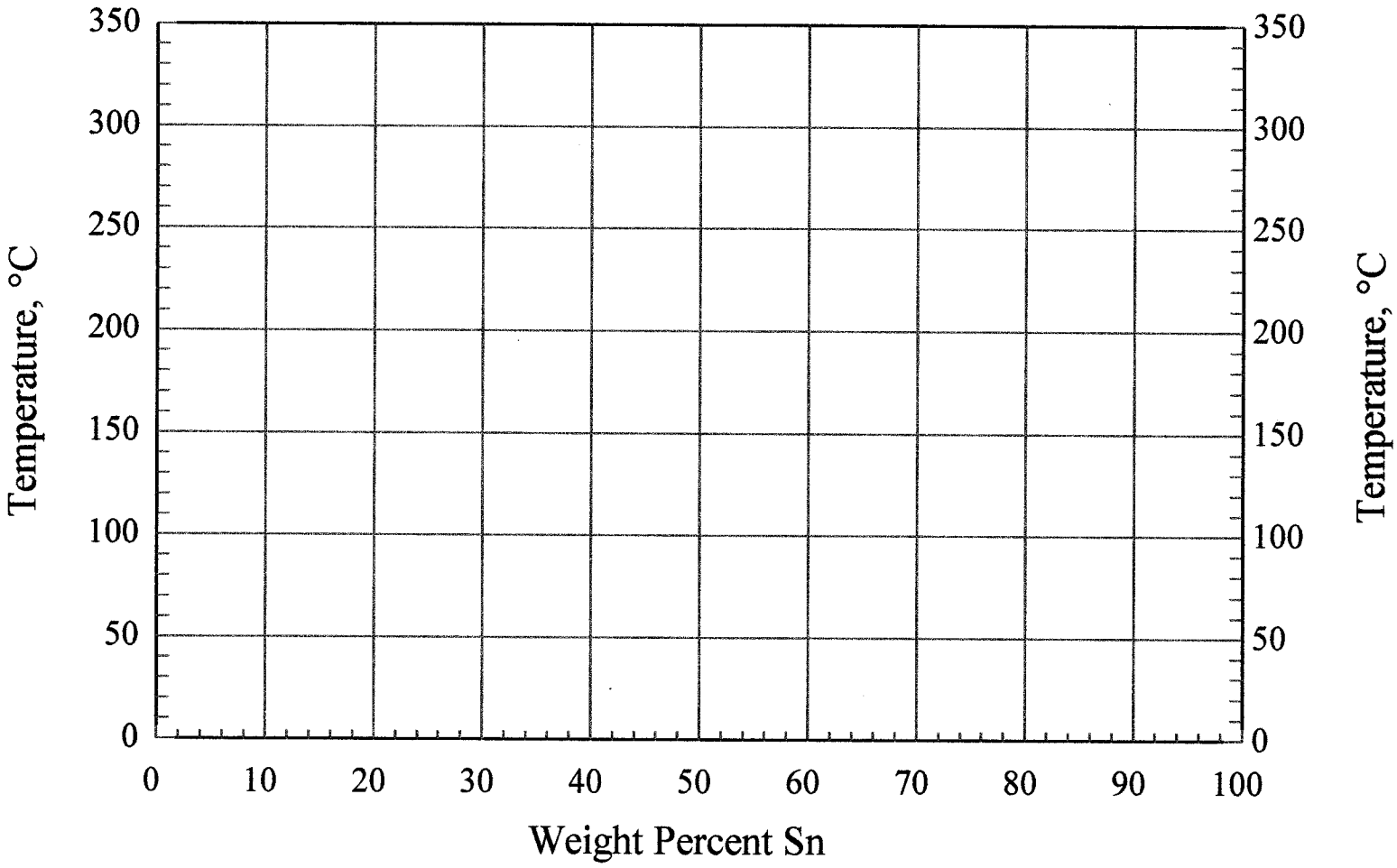
Compositions are given in weight percent.

Analysis of the Cooling Curves

Nominal Composition	Transition Temperature 1 °C	Transition Temperature 2 °C	Transition Temperature 3 °C	Typical Temperature Error, °C
0/100				
10/90				
20/80				
30/70				
40/60				
50/50				
60/40				
70/30				
80/20				
90/10				
100/0				

Compositions are given in weight percent.

Phase diagram:



Thermocouples

Characteristics of Thermocouples

Type	+ Leg	- Leg	Range, °C	Limits of Error	Environment	Comments
E	Chromel (Ni-10Cr)	Constantan	-200 - 900	Above 0°C: ±0.5% or ±1.7°C Below 0°C: ±1.0% or ±1.7°C	Oxidizing or inert, limited use in vacuum or reducing	Highest EMF change per degree.
J	Iron	Constantan	0 - 750	±0.75% or ±2.2 °C	Reducing, vacuum, or inert, limited use in oxidizing	Not recommended for low temperatures.
K	Chromel (Ni-10Cr)	Alumel Ni-5(Al, Si)	-200 - 1250	Above 0°C: ±0.75% or ±2.2 °C Below 0°C: ±2.0% or ±2.2°C	Clean oxidizing or inert, limited use in vacuum or reducing	Wide temperature range, most popular calibration
R	Platinum-13% Rhodium	Platinum	0 - 1450	±0.25% or ±1.5 °C	Inert or oxidizing. Do not use metal protection tubes. Avoid contamination.	Low EMF change, high temperature
S	Platinum-10% Rhodium	Platinum	0 - 1450	±0.25% or ±1.5 °C	Inert or oxidizing. Do not use metal protection tubes. Avoid contamination.	Low EMF change, high temperature
T	Copper	Constantan	-200 - 350	Above 0°C: ±0.75% or ±1.0°C Below 0°C: ±1.5% or ±1.0°C	Mild oxidizing, reducing vacuum or inert. Good where moisture is present.	Low temperature and cryogenic applications

Reference: Omega Engineering's *Temperature Handbook.*

NIST Polynomial Coefficients

Type	E	J	K	R	S	T
Range	-100°C - 1000°C	0°C - 760°C	0°C - 1370°C	0°C - 1000°C	0°C - 1750°C	-160°C - 400°C
Error	±0.5°C	±0.7°C	±0.7°C	±0.5°C	±1.0°C	±0.5°C
a_0	0.104967248	-0.048868252	0.226584602	0.263632917	0.927763167	0.100860910
a_1	17189.45282	19873.14503	24152.10900	179075.491	169526.5150	25727.94369
a_2	-282639.0850	-218614.5353	67233.4248	-48840341.37	-31568363.94	-767345.8295
a_3	12695339.5	11569199.78	2210340.682	1.90002×10^{10}	8990730663	78025595.81
a_4	-448703048.6	-264917531.4	-860963914.9	-4.82704×10^{12}	-1.63565×10^{12}	-9247486589
a_5	1.10822×10^{10}	2018441314	4.83506×10^{10}	7.62091×10^{14}	1.88027×10^{14}	6.97688×10^{11}
a_6	-1.76807×10^{11}		-1.18452×10^{12}	-7.20026×10^{16}	-1.37241×10^{16}	-2.66192×10^{13}
a_7	1.7842×10^{12}		1.38690×10^{13}	3.71496×10^{18}	6.17501×10^{17}	3.94078×10^{14}
a_8	-9.12978×10^{12}		-6.33708×10^{13}	-8.03104×10^{19}	-1.56105×10^{19}	
a_9	2.06132×10^{13}				1.69535×10^{20}	

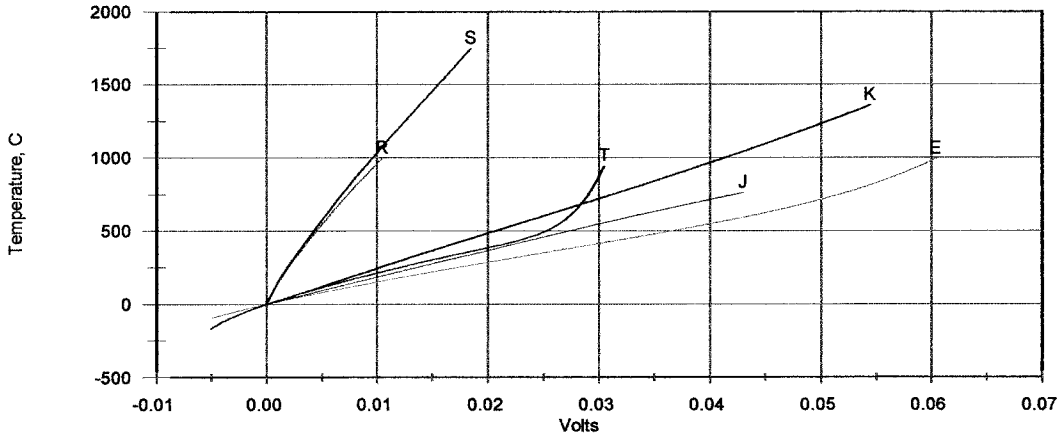
Reference: Hewlett-Packard's application note 290, *Practical Temperature Measurements*, page 8.

Standard Polynomial Form

$$T = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \ \ldots \ a_n x^n$$

Nested Polynomial Form

$$T = a_0 + x(a_1 + x(a_2 + x(a_3 + x(a_4 + x a_5)))) \quad (5^{th} order)$$



EMF-temperature characteristics of the thermocouples in the above tables.

Instructor's Appendix

Comments: We have used this experiment, in its current form, in our sophomore level introductory materials science course for about 6 years. Judging from the quality of the results, the reports, and the fact that everyone finishes in time, the experiment is almost always successful. It is also our first group experiment of the quarter, one which requires that the students share their results, critique each other's results and help each other perform the experiment and generate the graphs. At the end of the class we gather around the white board, were the students have entered their data in a large table, to review the results, make necessary corrections, etc.

This is our one experiment which requires that the students have a good idea of what the results will be like before they start collecting data. They must study a phase diagram to find out what the minimum temperature of the molten metal must be before removing it from the heater, and they must decide at what temperature they can stop taking data. Having done this they monitor the cooling curves closely looking for signs of the expected phase transformations.

We use an older computer for the data acquisition and for constructing the cooling curves. The data acquisition program was written in QuickBASIC program and runs under DOS. It presents the students with a series of screens where the students can view and change data acquisition parameters. It was designed to not only collect the data but also to introduce them to the major issues in digital data acquisition. It includes a demo-mode to allow the students and the instructor try out the program without actually having to collect data. This feature is particularly useful when the instructor is showing the students how to use the program.

The cooling curves are produced by a spreadsheet program (Quattro Pro 5) which has predefined macros that help the students import, display and print the data. They can even look at the data to determine the temperature and cooling rate at a particular time, for instance. This is the third time they have used spreadsheets in this course and by now that have a pretty good idea of how to use one. In this case we wanted to make the spreadsheet both useful and show them how one can use macros to perform complicated procedures.

Equipment, Parts and Supplies

Other than a PC the only major pieces of equipment are the electronic balance, the variac and the digital multimeter. The variac is rated for 10 amps at 120 volts. The multimeter is a Keithley Model 199 System DMM/Scanner. It is a digital multimeter which has a built in scanner capable of taking readings at 5½-digits resolution from 8 channels. It also has a IEEE-488 interface which makes it possible to control the DMM and read the data using a computer.

Thermocouples are type J. This is a good thermocouple for the temperature range in this experiment and it is not as common and as useful as the type K thermocouple so they don't tend to wander off.

The software used in the data collection and the spreadsheet used to import and display the data can be downloaded from www.matsci.ucdavis.edu. Go to the "Laboratory Teaching Program" page and look for the "NEW-Update 2000" link. Source code for the QuickBASIC program is included.

The total cost of setting up this experiment, excluding the equipment mentioned above, is just under $2000. The thermocouples and reference junctions are the major cost. Several were donated and we purchased the rest over a couple of years until we had enough to operate three stations, each with three thermocouples. The total cost of running this experiment is simply the cost of the bismuth and tin plus computer paper and an occasional battery for the reference junctions. A reasonable estimate for this is under $40.

The following table lists the other parts and supplies used to set up and carry out this experiment. Common parts, such as hook-up wire and a power cord, are not listed here.

Description	Quantity[Note 1]	Vendor	Part Number (Quantity)	Cost Each	Extended Cost
Consumable Supplies					
Bismuth Shot (500 grams)	80 grams[Note 2]	Aldrich Chemical	26547-0 (1)	$80.10	$80.10
Granular Tin (500 grams)	80 grams[Note 2]	Aldrich Chemical	24343-4 (1)	$101.70	$101.70
Test tubes (colored labels, 1000/case)	16	Fischer Scientific	14-957-24A, B, C (3)	$59.25	$177.75
Weigh Boats, medium size (500/pkg)	2	VWR Scientific	12577-027 (1)	$47.25	$47.25

Miscellaneous Parts and Supplies					
Test Tube Clamps (10/pkg)	9	VWR Scientific	21770-028 (9)	$51.25	$51.25
Test Tube Rack (Stainless Steel)	4	VWR Scientific	60905-306 (4)	$15.95	$63.80
600 ml Beaker (6/box)	9	Fischer Scientific	02-540M (2)	$25.20	$50.40
Glass Wool	1	Fischer Scientific	11-390 (1)	$23.00	$23.00
Temperature Measurement Parts					
Thermocouple Assembly	9	Omega Engineering	JQIN-18G-6 (9)	$26	$234.00
Thermocouple Reference Junction	9	Omega Engineering	MCJ-J (9)	$99	$891.00
Thermocouple Extension Wire	50 feet	Omega Engineering	EXPP-J-24S (50)	$0.29/foot	$14.50
Thermocouple Quick Connects, M/F Pair	9	Omega Engineering	OSTW-J-MF (9)	$7.65	$68.85
Rubber Grommets (⅛" ID, ¼" OD, 100/pkg)	18	Newark Electronics	31F2000 (1)	$5.84	$5.84
Parts Used to Make the Heater					
Nichrome wire, 18 gage	100 feet	McMaster-Carr	8880K15 (1)	$13.04	$13.04
Fish Spines (500)	1	Omega Engineering	FS-200-14 (1)	$12.00	$12.00
Ceramic thermocouple protection tube	4	Omega Engineering	PTRM 341-6 (4)	$32.00	$128.00
Illuminated Rocker Switch, 10 Amp	1	Radio Shack	275-692 (1)	$2.69	$2.69
Panel Mount Fuse Holder	1	Radio Shack	270-374 (1)	$1.59	$1.59
7 Amp Fuse, Fast Acting	1	Radio Shack	270-1013 (1)	$1.29	$1.29

Note 1: The quantities listed in this column refers to the number or amount of material needed to set up or conduct the experiment. The quantity or number per package is given in the descriptions column. Note 2: This amount assumes 16 samples, each 10 grams, are mixed and analyzed.

Test Tube Heater

Description

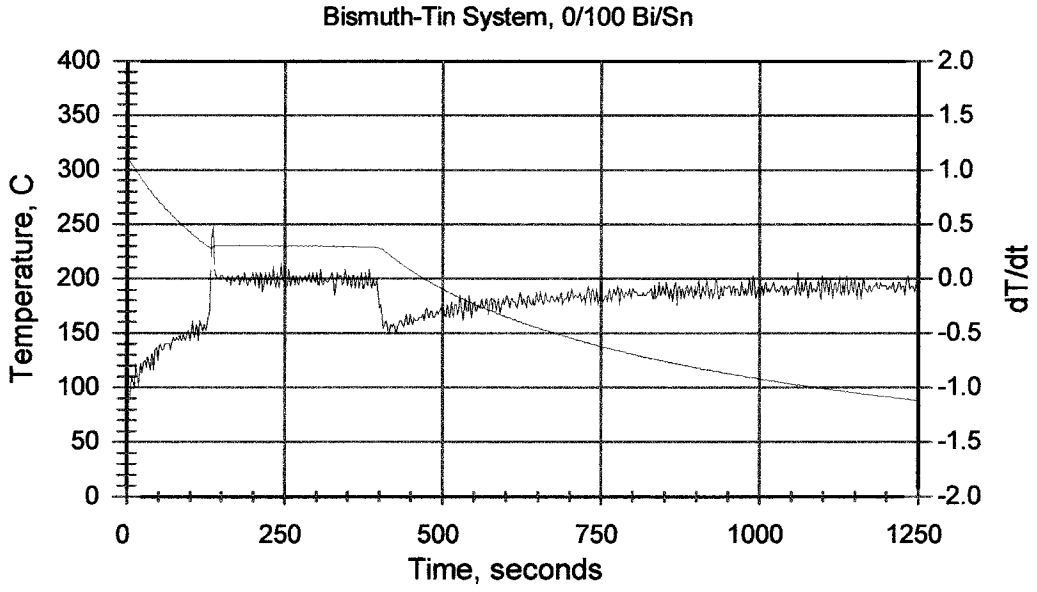
A suitable heater could not be purchased so I made my own. The heating elements are simply four ceramic tubes wound with 18 gage nichrome wire and separated by ceramic fish spines to prevent short circuits. These are put in an insulated box which is put into another box. There is a gap between these boxes and a gap at the top to allow air to flow between them, keeping the outer box cool. Everything is wired together and a switch and fuse holder are mounted in the outer box. To operate it one plugs it into a variac which is set to about 30 volts. This is sufficient power to obtain temperatures close to 400°C, hot enough to melt the sample in 5-10 minutes. A separate thermocouple and meter are used to monitor the temperature.

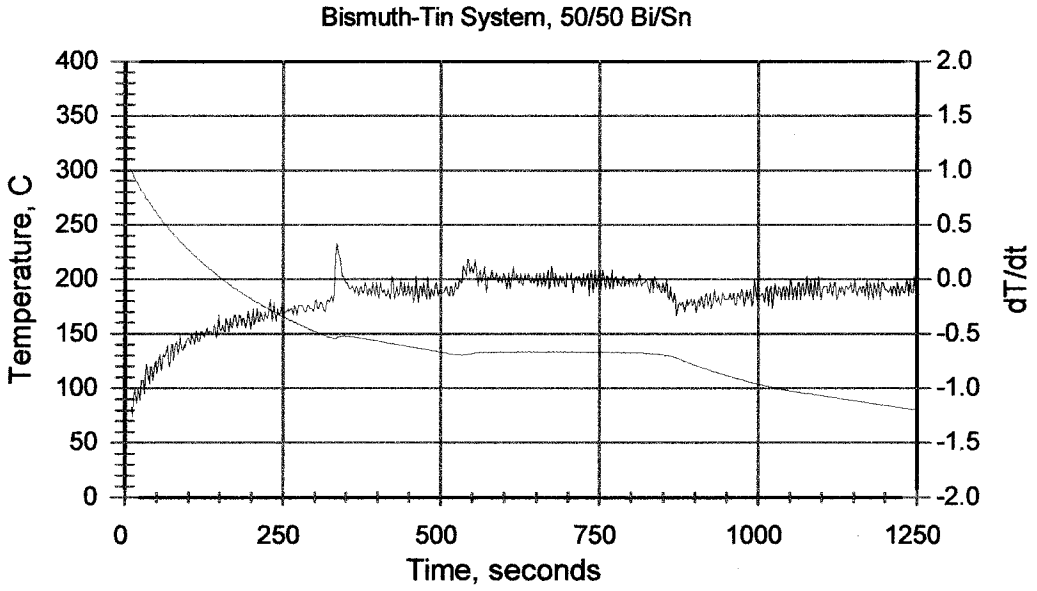
Construction of the Heater

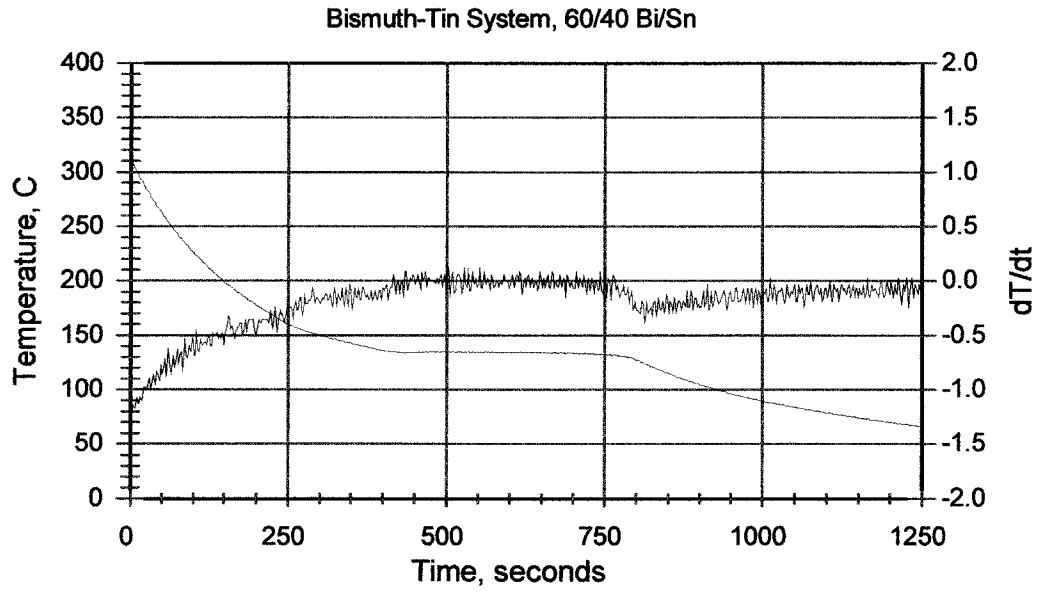
1. Make four heating elements using a procedure similar to the one below.
   a. Chuck up a 0.75 inch rod in a lathe. Turn the rod at a low speed, 5 to 15 rpm.
   b. Wrap about 25 feet of the nichrome wire around the rod. Keep enough tension on the wire while winding it so that it does not uncoil when you are finished.
   c. Remove the rod from the wire and slip the wire off the rod. It should remain coiled.
   d. Straighten about 10 inches of the nichrome wire. Double it back and twist it.
   e. Slip the wire over the thermocouple protection tube.
   f. Slip the fish spines over the wire so that the 25 revolutions of the wire are covered.
   g. Straighten the about 10 inches of wire and cut the wire. Double it back and twist it.
2. Find a suitable metal enclosure. I used and older instrument cabinet/project box turned it up on its back so that the open front panel becomes the top.
3. Make a steel liner. It should fit within the outer box with about an inch of clearance and should have a stainless steel top that has four holes where the ceramic tube will come through.
4. Install the heating elements in the inner box, connecting them in series, and end wires coming out of the liner. Fill the liner with ceramic wool or another suitable insulating material.
5. Install the liner in the main enclosure in such a way that minimal contact with the main enclosure is made. Mine was mounted using four screws and four half-inch standoffs.
6. Finish the wiring, install the power switch and fuse holder. Use copper wire to connect the heating elements to the switch and fuse holder.
7. Use a perforated metal sheet to close the bottom so that no one can be shocked yet air can flow through.
8. Place a bit of soft insulating material in the bottoms of the ceramic tubes. This will help prevent breakage of the test tubes.

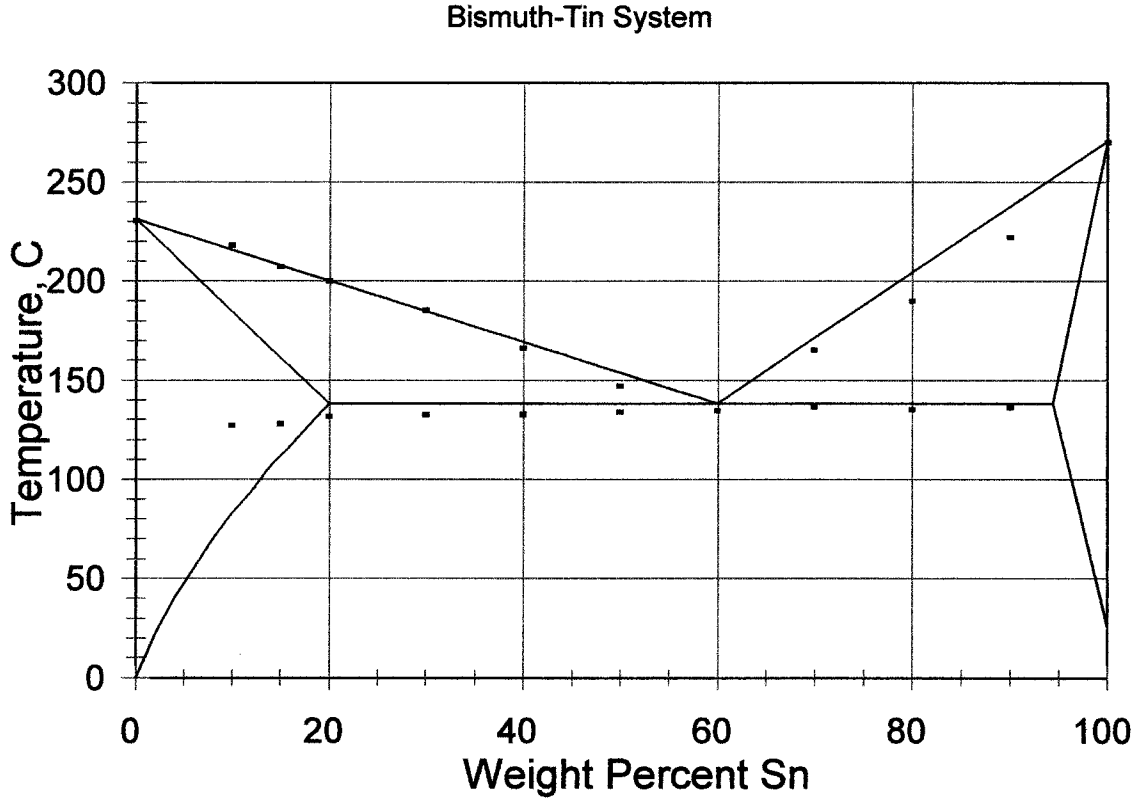
Sample Results

The following figures show a sampling of results, warts and all, generated by the students.



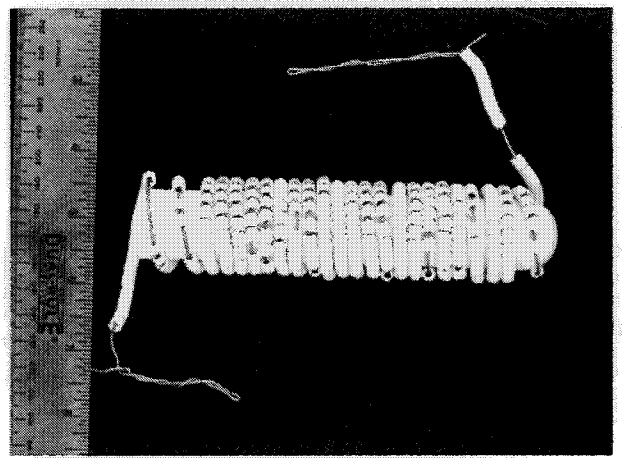



Bismuth-Tin System, 60/40 Bi/Sn
Temperature, C
dT/dt
Time, seconds
400
350
300
250
200
150
100
50
0
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
0
250
500
750
1000
1250

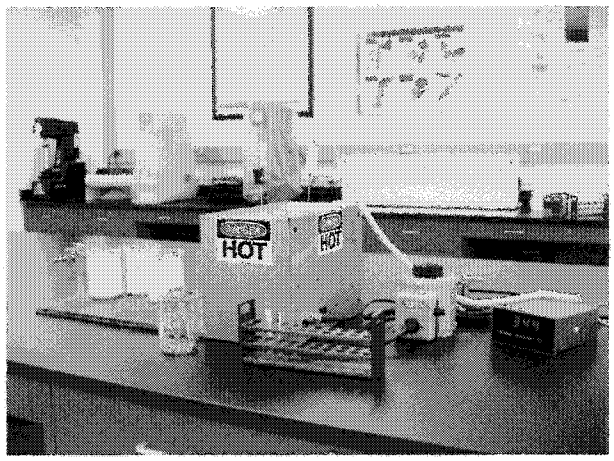

Bismuth-Tin System
Temperature, C
Weight Percent Sn
300
250
200
150
100
50
0
0
20
40
60
80
100

Experimental Apparatus

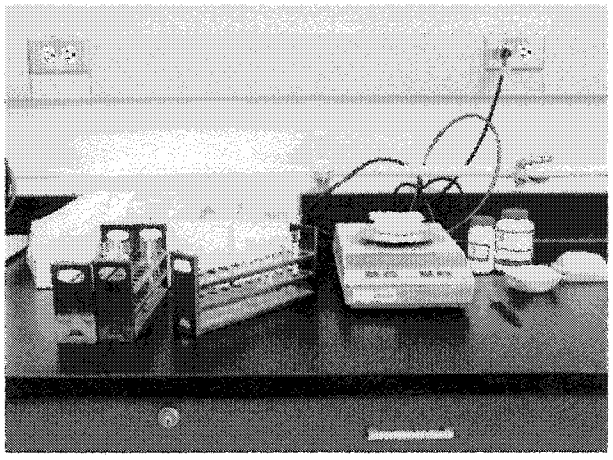
The figures below show several scenes from the laboratory.



Heating element. Four were used in our heater.



Heating station: showing the heater, variac, temperature readout, samples and test tube clamps.



Weighing station: showing the electronic balance, weigh boats, bismuth and tin, and test tubes.

Cooling Station: showing the computer, the multimeter, and three samples cooling in their insulated beakers.

RELATING ATOMIC BONDING FORCE AND ENERGY CURVES WITH OBSERVED MATERIAL PROPERTIES

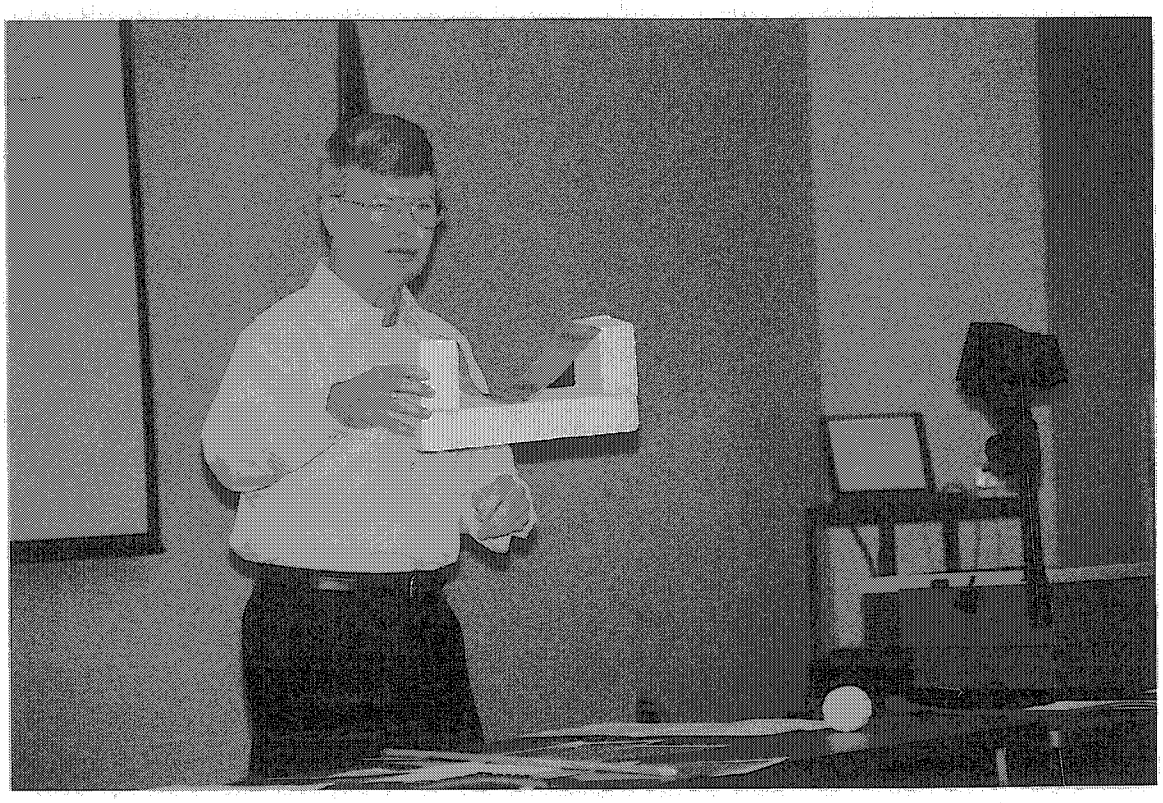
Robert A. McCoy

Professor of Materials Engineering
Youngstown State University
Youngstown, Ohio 44555

Telephone 330-742-1736
e-mail ramccoy@cc.ysu.edu

Biography:

Robert A. McCoy is a Professor of Materials and Mechanical Engineering at Youngstown State University, Youngstown, Ohio. He has bachelor's and master's degrees from Ohio State University and a Doctor of Engineering degree from University of California at Berkeley. At YSU, he teaches freshmen engineering, mechanical engineering, manufacturing processes, and materials engineering courses. He is also a failure analysis consultant and a member of ASM and ASEE.



Relating Atomic Bonding Force and Energy Curves with Observed Material Properties

Robert A. McCoy
Professor of Materials Engineering
Youngstown State University
Youngstown, Ohio

Key Words: Atomic bonding force, atomic bonding energy, elastic modulus, cleavage strength, thermal expansion.

Prerequisite Knowledge: Basic knowledge of electrostatic attractive forces, the relation between force and energy, integration and differentiation of a polynomial, and mechanical properties determined from a tensile test.

Objective: To understand the relationships between the atomic bonding force, the atomic bonding energy, basic mechanical properties, and thermal expansion of solids.

Equipment:

1. Tennis-ball model: two tennis balls and four wide rubber bands
2. Halfpipe model: tin can 4-inch dia. & 4-inch ht., foamed polystyrene 22x4x2 inch, small ball
3. A computer with a MS Excel

Introduction:

To gain a better understanding of the basis of the common mechanical properties of solids, three approaches are presented to the students jointly:

1. A mathematical expression for the atomic bonding force followed by integration to obtain the potential energy expression and the use of these equations to obtain various mechanical properties.
2. Plots of the force and energy curves to obtain graphical solutions.
3. Use of a tennis-ball model and a halfpipe model to illustrate physical relations.

Procedure:

The class is assigned the following project, either to be worked out as individuals or as small groups of two or three students each. For a K^+ and Cl^- ion pair, the electrostatic attractive force due to opposite charges and the repulsive force due to overlapping outer electron shells depend upon the distance between centers of the ions, r, according to the equations:[1] $F_A = 1.436 \times r^{-2}$ and $F_R = -5.274 \times 10^{-5} \times r^{-10}$. For these equations, the forces are in units of electron volts per nanometer (eV/nm) and r is the distance in nanometers (nm). The net force F_N acting on the ion pair is just the sum of the two forces. Proceed as follows:

a) Use MS Excel to plot the equation for F_N versus r from 0.2 up to 0.6 nm. Adjust your Y-axis scale so its range is from –6 up to 10. Quantify and label both coordinates.
b) Potential energy, PE, is the integral of the F_N with zero potential energy defined as when the ions are separated at infinite distance. Therefore, $PE = \int F_N \, dr$. Solve the integral to obtain an expression for PE and use MS Excel to plot this equation versus r from 0.2 up to 0.6 nm. Again, adjust your Y-axis scale so its range is from –6 up to 10. Quantify and label both coordinates.
c) Graphically determine the equilibrium spacing between the two ions, r_o, first using the F_N curve and then using the PE curve.
d) Mathematically solve for r_o, first using the F_N equation and then using the PE equation.
e) Mathematically solve for the minimum potential energy, PE_o, and compare it with the value obtained graphically. This value corresponds to the equilibrium bond energy of the ion pair at absolute zero temperature where the ions possess zero kinetic energy.
f) Mathematically solve for the maximum force, F_{max}, and compare it with the value obtained graphically. F_{max} correlates with the cleavage strength of the material.
g) Mathematically solve for the slope of the F_N curve as it passes through zero. This slope measures the ratio of an applied external force to the resulting increase in separation from r_o. Therefore, this slope correlates with the elastic modulus of the material, E, a measure of a material's stiffness.

The graphical solutions for parts a, b, and c can be found in Figure 1. Answers to the mathematical problems are:

b) $PE = \int F_N \, dr = -1.436 \times r^{-1} + 5.86 \times 10^{-6} \times r^{-9}$
d) $r_o = 0.279$ nm
e) $PE_o = -4.575$ eV
f) $F_{max} = 9.87$ eV/nm
g) $E = 529$ eV/nm^2

Comments:

To help introduce the idea of the balance between the attractive force and the repulsive force, the instructor may use two tennis balls with three or four wide rubber bands wrapped around them, as shown in Figure 2. The tension of the rubber bands represents the attractive atomic bond force and the resistance of the balls to being smashed corresponds to the repulsive force resulting from the outermost electronic shells of the two ions beginning to overlap. The equilibrium spacing between the atoms or ions, r_o, corresponds to the slightly smashed together configuration of the tennis balls pulled together by the rubber bands.

The elastic modulus of the ion pair which is found from the slope of the force curve in the region of r_o correlates with the increase in external force needed to pull the tennis balls apart a unit distance from their equilibrium distance. The cleavage strength of the ion pair which is found where the force curve reaches a maximum value F_{max} correlates with the external force required to break the first rubber band. One may assume that once the first rubber band breaks, the other rubber bands will be overloaded and break in a chain reaction.

The bond energy of the ion pair correlates to the amount of stored spring potential energy of the rubber bands in their equilibrium position of holding the balls together. Thermal energy of the ion pair correlates with the amount of their vibrational energy. The greater the temperature, the larger the amplitude of vibration. At some temperature above absolute zero, the ion pair vibrates between r_{max}, the largest separation distance and r_{min}, the smallest separation distance. The way that the kinetic energy of the ion pair is converted to potential energy and back again as the ion pair vibrates between r_{max} and r_{min} can be visualized by using the analogy of a ball rolling up and down the walls of a rounded trough. Students will more readily identify with skateboarding in a halfpipe. A halfpipe model can be constructed from a tin can and some foamed polystyrene, as shown in Figure 3. Instead of being a half circle in cross-section, the cut-open tin can is bent into the skewed shape of the potential energy curve seen in Figure 1. When a ball is released in this skewed halfpipe model, it rolls back and forth up to approximately equal heights on each side, converting its kinetic energy into gravitational potential energy, analogous to converting vibrational kinetic energy to the bonding potential energy of the ion pair.

Thermal expansion is the result of combining the larger amplitude of vibration at higher temperatures along with the nonsymmetrical shape of the energy curve. Referring to the halfpipe model, the higher the temperature, the higher the ball rolls up on each side of the trough. If it is assumed that the average spacing between atoms at some particular temperature is given by $\frac{1}{2}(r_{max} + r_{min})$, one can see that as the temperature increases, this average spacing increases above the equilibrium spacing due to the nonsymmetrical nature of the energy curve, as shown by the dashed line in Figure 1.

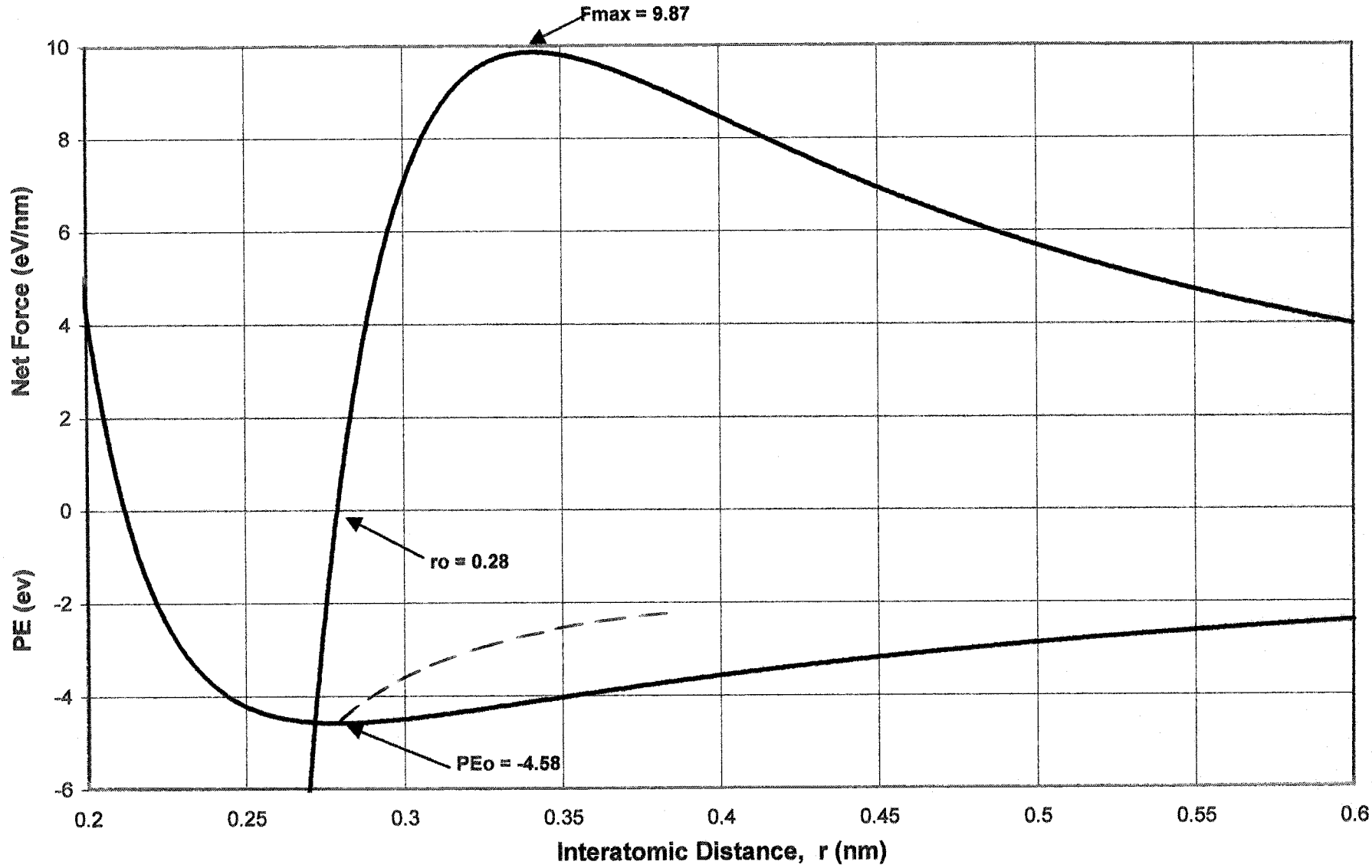
Following the presentation of the relations discussed above, the instructor should now ask the students what are the effects of increasing bond strength on the various observed material properties. These effects can be observed by having the students repeat the steps in the procedure section, only this time double the magnitude of F_A so that $F_A = 2.872 \times r^{-2}$. When plotting this revised equation, the students need to change the range of the Y-axis, as seen in Figure 4. Specifically the students should observe that as bond strength increases, the F_N curve shifts up and to the left whereas the PE curve dips lower and to the left and becomes more symmetrical. The dashed lines shown in Figure 4 indicate the average atomic spacing as the temperature increases. These observations should allow the students to deduce that as bond strength increases,

a) the equilibrium spacing, r_o, decreases
b) the elastic modulus, E, increases
c) the cleavage strength, F_{max}, increases
d) both the equilibrium bond strength, PE_o, and the melting point increase
e) the thermal expansion effect decreases

References:

1. W. Callister, Materials Science & Engineering: An Introduction, John Wiley & Sons (2000).

Figure 1. Net Force & Potential Energy versus Interatomic Distance



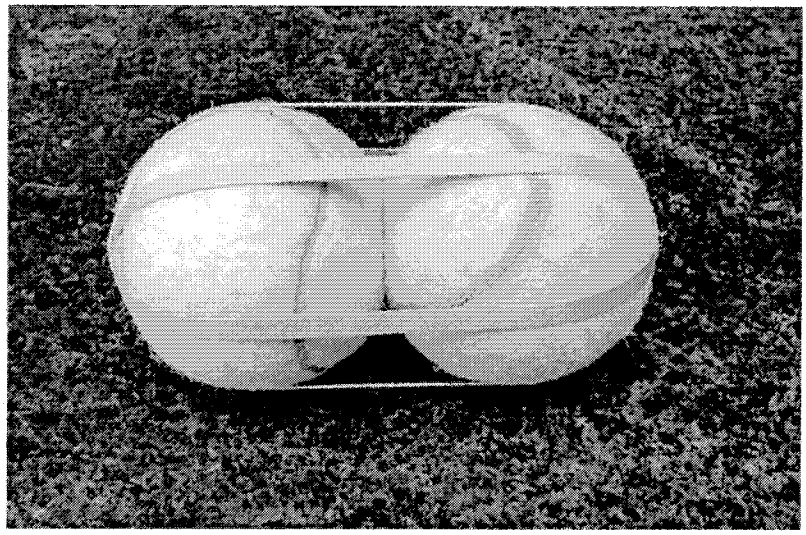


Figure 2. Tennis-ball Model

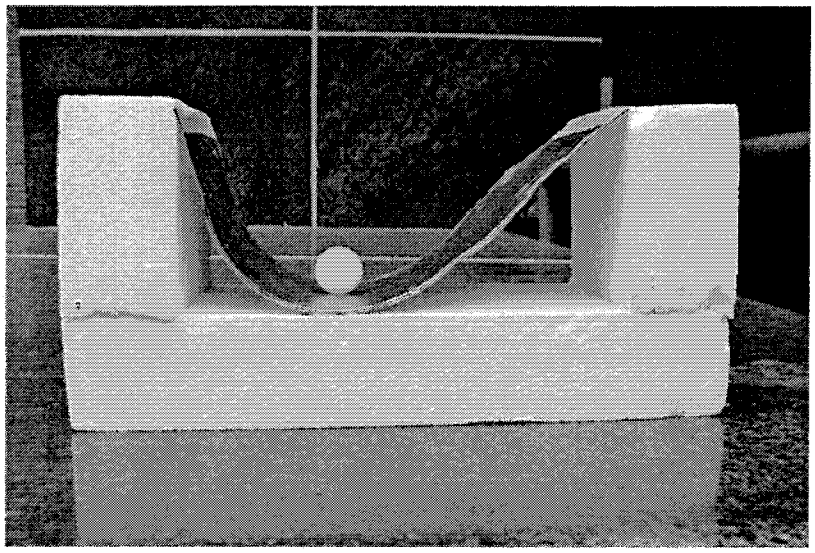
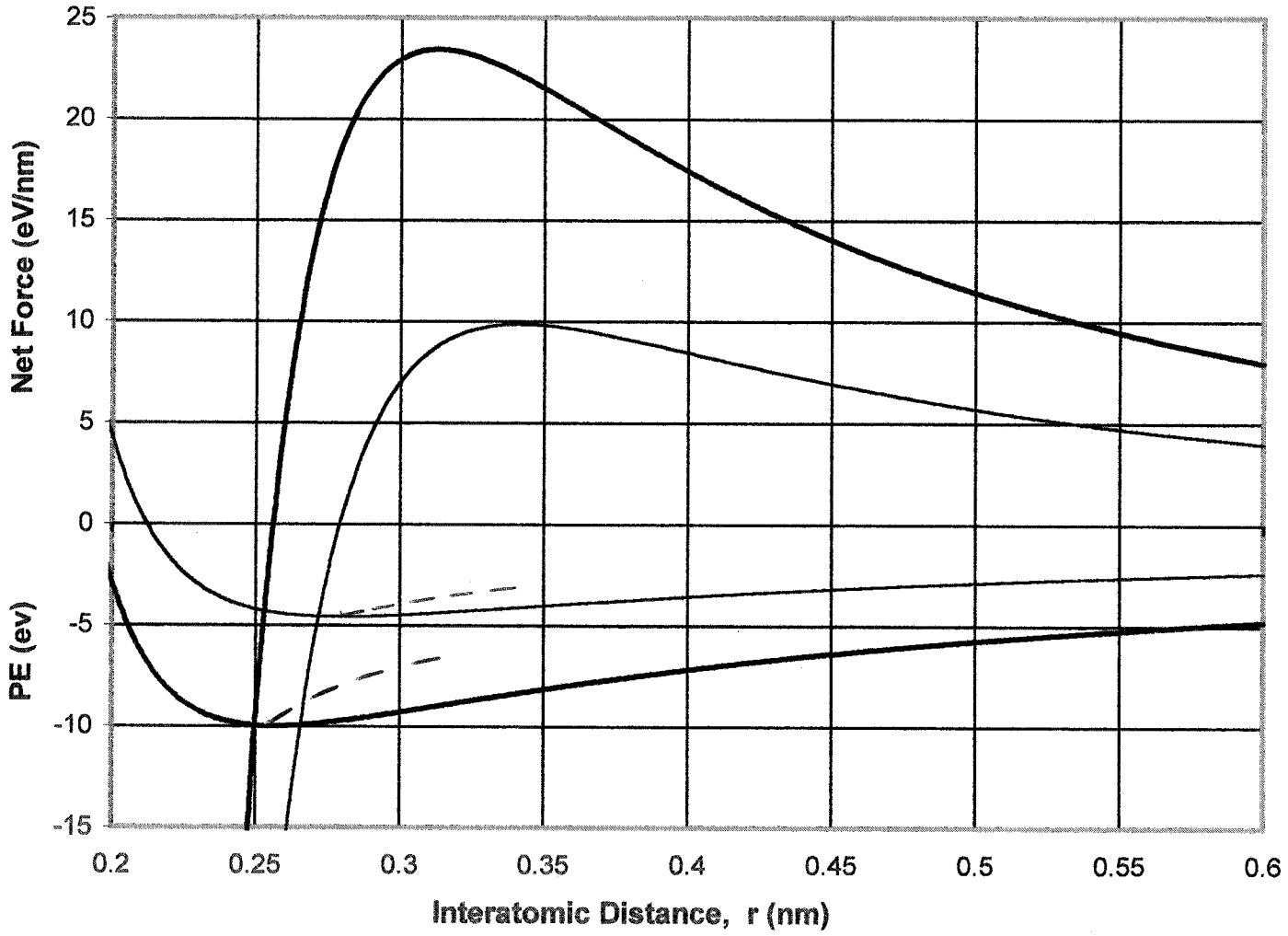


Figure 3. Halfpipe model

Figure 4. Force & Energy vs Interatomic Distance for Strong & Weak Bonds



Heavy lines for a strong bond and thin lines for a weak bond

THE BRAGG BUBBLE RAFT FILM

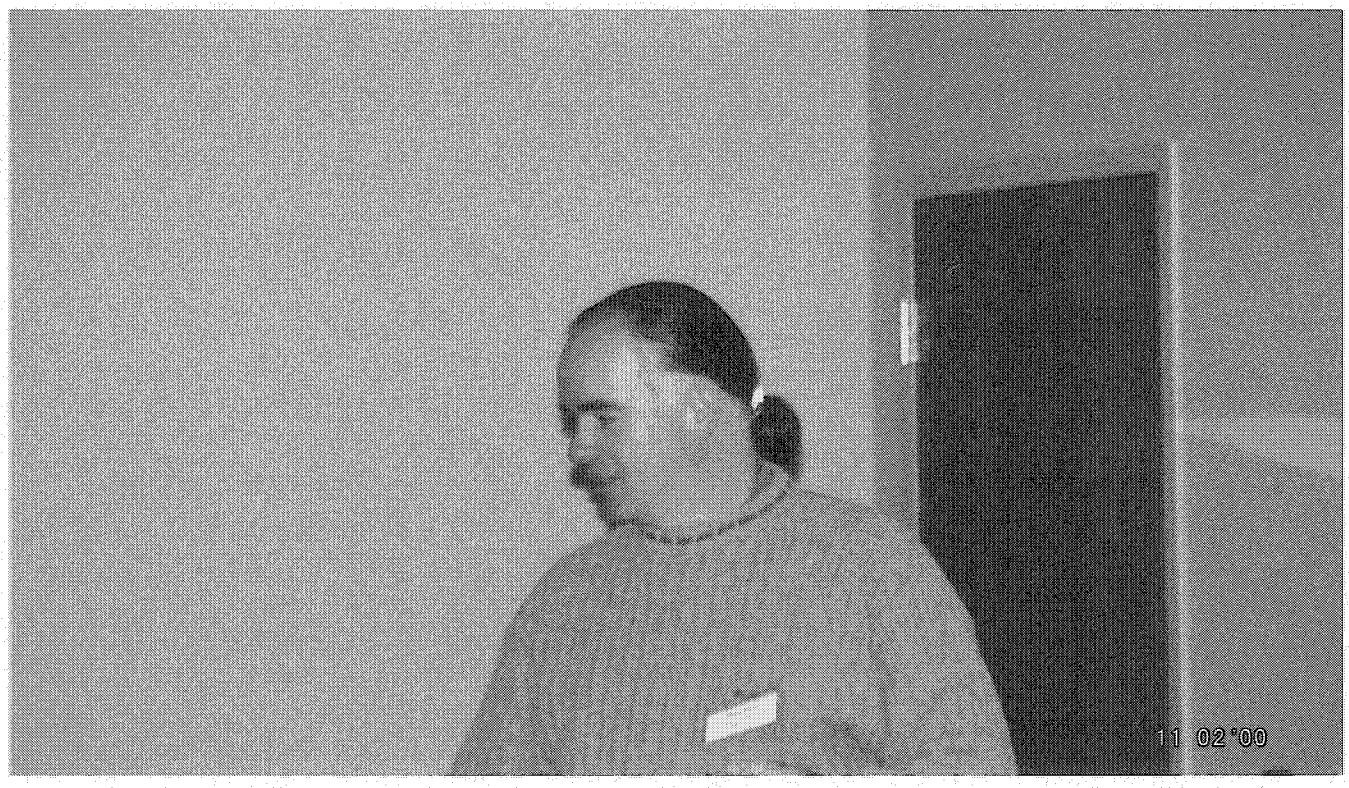
Mike Meier

Department of Chemical Engineering and Materials Science
University of California, Davis
Davis, California 95616

Telephone: 530-752-5166
e-mail mlmeier@ucdavis.edu

Biography:

Michael L. Meier received his B.S. in Materials Engineering from North Carolina State University in 1979 and his M.S. (1986) and Ph.D. (1991) in Materials Science and Engineering from the University of California, Davis. After a two-year post-doctorate position at the Universität Erlangen-Nürnberg in Erlangen, Germany he returned to UC Davis where he is the director of Materials Science Central Facilities and teaches many of the laboratory courses.



THE BRAGG BUBBLE RAFT FILM

Mike Meier
Department of Chemical Engineering and Materials Science
University of California, Davis
Davis, CA 95616
USA

Key Words: crystalline lattice, plastic deformation, dislocations, slip, grain boundary, tilt boundary, recrystallization, vacancies, bubble raft

Prerequisite Knowledge: Familiarity with the nature of the crystalline lattice, dislocations and their role in plastic deformation, and mechanisms of dislocation motion and interaction with other lattice defects.

Objective: The objective here is to show instructors a film that they would surely find useful in their mechanical properties courses, if they could find it.

Equipment and Materials: You'll need either a film projector or a VCR, depending on the format of your copy.

Introduction:
The title of the film is Experiments with the Bubble Model of a Metal Structure. The authors, narrators and actors are Sir Lawrence Bragg, W.M. Lomer and J.F. Nye, the film was made in 1954, and it was produced by N.S. MacQueen. I have been unable to determine who is currently distributing this film, but at one time it was distributed by MacQueen Film Organisation, Kent England, and in the mid-1980's it was distributed in parts by Ealing Film-Loops, Cambridge, Massachuttes. Segments of this film have also been used in John Russ's CD [1]. A search of the web has not turned up any new information regarding the availability of this film, but responses to my queries in the internet discussion groups alt.metallurgy and alt.materials indicate that the people who have seen the film really admired it, and at least one other copy can be found a the University of Pennsylvania in Philadelphia, PA. My web search did turn up a number of sites describing the use of the bubble raft model in the classroom. It seems that the idea of the bubble raft model of the structure and deformation of a metal is much better known that this film.

The film starts by introducing the concept of a metal as atoms in regular patterns, the crystalline lattice. It then introduces the bubble raft model by stating that the forces that hold bubbles together are very similar to those which hold atoms together, and that one can construct a bubble raft model using a soap solution and a carefully controlled jet of air. The film shows the raft, representing a perfect lattice, then goes on to show grains and grain boundaries until it gets to the main point, the role of dislocations in plastic deformation. Several frames from this film are shown at the end of this paper.

Procedure:

The one time I showed this film in class I had just spent two weeks describing dislocations, strain fields around dislocations, interactions between dislocations, vacancies and solute atoms, the formation of tilt boundaries, the mobility of subgrain boundaries, etc. I sensed that at the end of these lecture the students had heard about all of these things, that it all seemed logical enough, but were still not real to them. After the film was over their faces had changed. Dislocations were real, and they did all of the things I had described, sketched on the black board, etc. They were really impressed by how nimble the dislocations were. They could move so quickly, and yet the bubbles themselves hardly moved at all, unless one watched many dislocations moving for a period of time. The theory of dislocations really could explain plastic deformation!

Comments:

I intend to continue my search for information (historical and availability) on this film and will post my findings on our web site at www.matsci.ucdavis.edu.

References:

1. J.Russ, Materials Science: A Multimedia Approach, PWS Publishing Co., (1996).

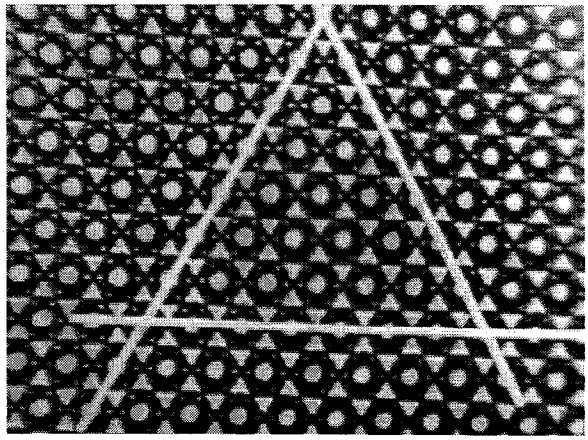


Figure 1 Perfect crystalline lattice.

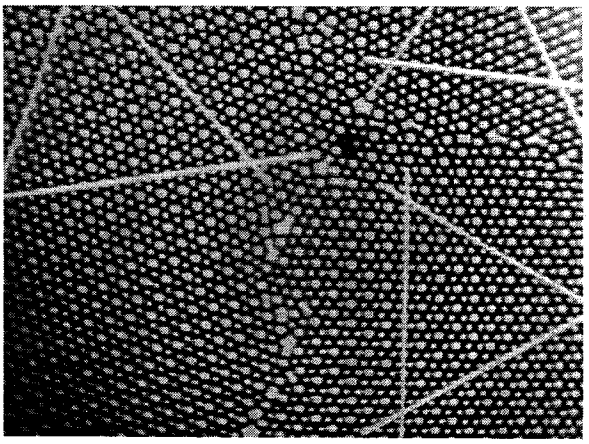


Figure 2 Grains and grain boundaries.

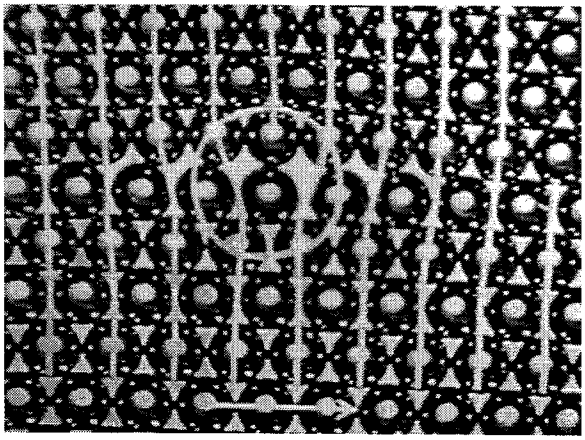


Figure 3 An edge dislocation.

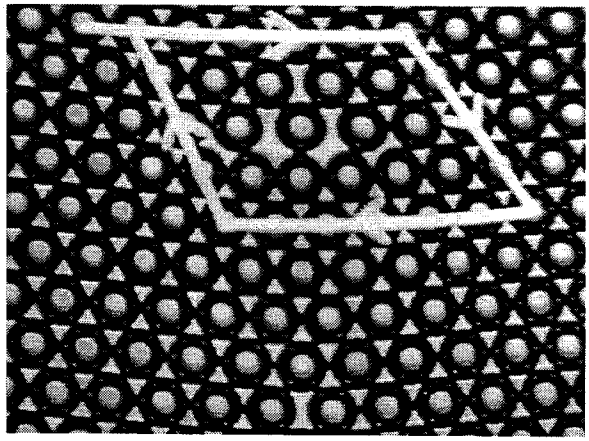


Figure 4 The Burger's circuit.

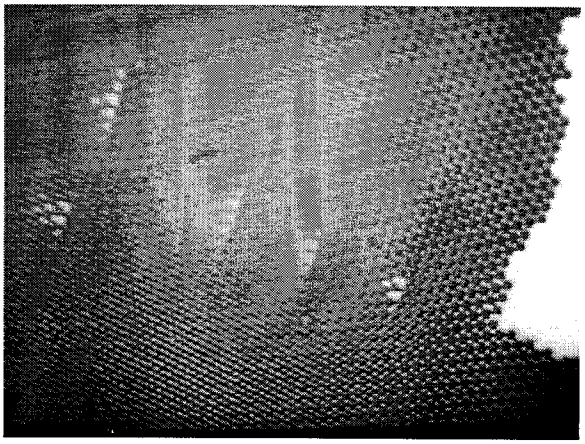


Figure 5 Interactions between dislocations.

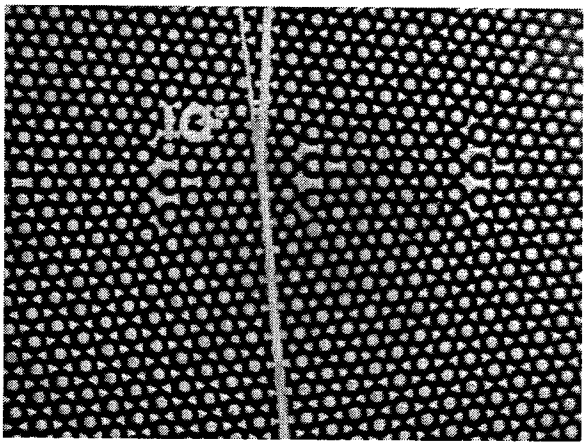


Figure 6 Low angle boundary.

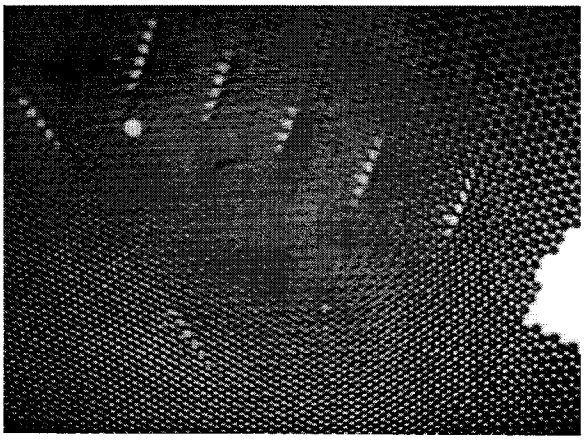


Figure 7 Subgrain boundary migration.

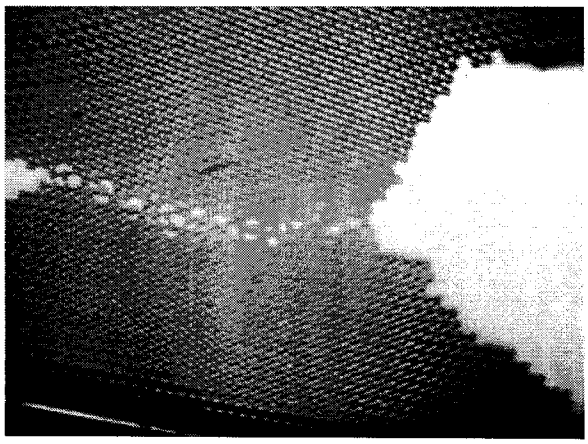


Figure 8 Grain boundary shear.

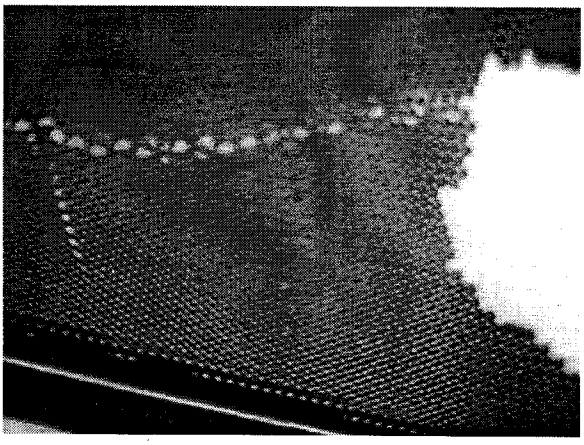


Figure 9 Grain boundary sliding and migration.

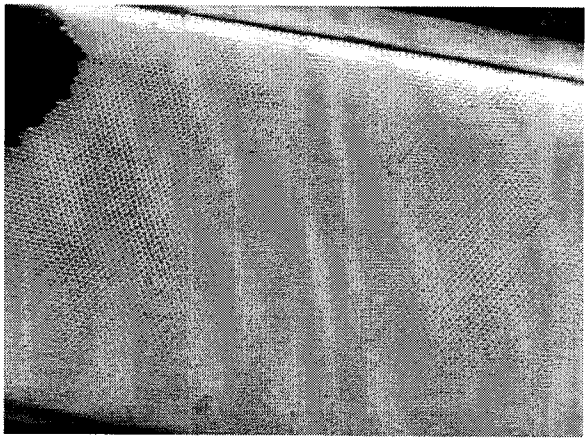


Figure 10 Plastic deformation.

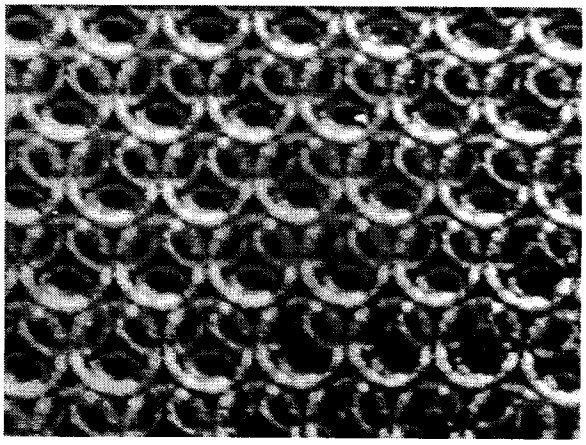


Figure 11 Three-dimensional bubble raft.

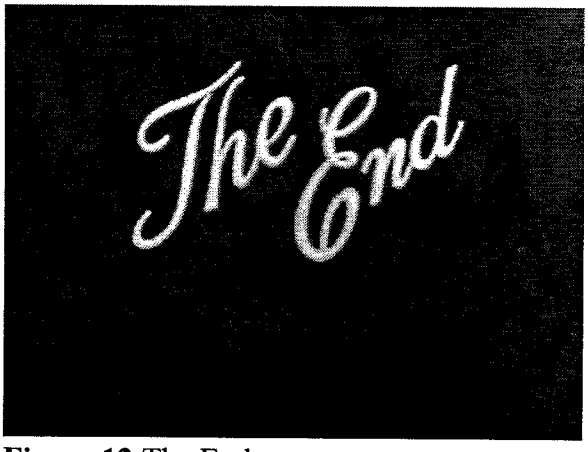


Figure 12 The End.

GALVANOSTATIC POLARIZATION CURVES FOR TEACHING PURPOSES PART III

Carlos E. Umana

Department of Materials
School of Mechanical Engineering
University of Costa Rica
San Jose, Costa Rica

Telephone: 506-207-4548
e-mail caruma@terraba.fing.ucr.ac.cr

GALVANOSTATIC POLARIZATION CURVES FOR TEACHING PURPOSES PART III

Carlos E. Umaña
Departamento de Materiales
Escuela de Ingeniería Mecánica
Universidad de Costa Rica
San José, Costa Rica

KEY WORDS: Equilibrium potential, exchange current density, cathodic protection by external power supply.

PREREQUISITE KNOWLEDGE: A complete understanding of the theory and experimental work involved in parts I and II of this experiment (Ref.1 and Ref.2).

OBJECTIVES:

1. Explore the meaning of exchange current density.
2. Introduce the concept of Overpotential for Negligible Internal Current (OPNIC).

INTRODUCTION:

The first part of this experiment was presented at the NEW:Update 98 and the second part at the NEW:Update 99. All the experimental work was performed in both first and second stages. This third last part consists of an analysis that will be combined with the experimental results of part II, in order to complete an experimental and analytical presentation of all the basic parameters associated with experimental applied current curves and polarization diagrams.

As it was described in reference 1, the working electrode can be represented as one anodic area and one cathodic area, which are the result of gathering together all the small anodic and cathodic areas distributed within the working electrode surface. Figure 1 shows a schematic polarization diagram and a working electrode at corrosion potential and under either anodic or cathodic overpotential. The total current is the sum of both the applied and the internal current. As the total current increases the internal current approaches zero and the question is, at what overpotencial will the internal current be negligible? The following suggestions have been proposed in the literature (Ref.3) to define this overpotential, which in this work will be known as Overpotential for Negligible Internal Current (OPNIC):

1. The overpotencial is defined by the chemical equilibrium potential.
2. Apply an overpotential in between 100 and 300 mv.
3. For cathodic protection of steel, field experience defines an overpotential of -573 mv (versus SCE) in both seawater and soil.

In a solution as the one used in this experiment (deaerated 20 g/l NaCl, pH≈7), the anodic and the cathodic reactions and the corresponding chemical equilibrium potentials versus SCE are as follows (Ref.4):

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad E_o = -688\,mv$$

$$2H_2O + 2e^{-} \rightarrow 2OH + H_2 \qquad E_o = -654\,mv(pH \approx 7)$$

The corrosion potential obtained in part II was E_{corr} = -500 mv. Just as it is always observed in the corrosion literature, in this case the anodic equilibrium potential is also under the corrosion potential with a cathodic overpotential of -188 mv = - 688 mv - (-500 mv). However, and contrary to the common behavior, the cathodic equilibrium potential is also under the corrosion potential. This means that the corresponding overpotential is also negative and the exchange current density is larger than the corrosion current density. Two important conclusions can be derived from this result:

1. The chemical equilibrium potential does not define an OPNIC and therefore the exchange current density cannot be used as the limiting point of an anodic or cathodic reaction.
2. The exchange current density is more an electrochemical constant than a corrosion parameter of practical use.

The second approach is based on the fact that it has been observed that the OPNIC is usually around 100 to 300 mv. However this observation is useful only as a verification in connection with a more precise procedure.

The third suggestion gives a specific potential, which is equivalent to a cathodic overpotential of -273 mv for an E_{corr} = -500 mv. This value is within the overpotential range given before, but it should be remembered that this only applies for aerated solutions. Therefore in this experiment this overpotential can be used only as a reference.

INTERNAL AND TOTAL CURRENT DENSITY RELATION APPROACH

In this work a more rational approach is proposed to define an OPNIC value. It consists in comparing the internal current to the total current by using a prefix ratio "r" for an anodic or cathodic overpotential. The anodic coefficient r_a is expressed as:

$$r_a = \frac{i_{a,\text{int}}}{i_{a,tot}} \tag{1}$$

Where:

The anodic internal current density is given by $$i_{a,\text{int}} = i_{corr}\, e^{\frac{2.3\,\varepsilon_a}{\beta_c}} \tag{2}$$

and the anodic total current density is given by $$i_{a,tot} = i_{corr}\, e^{\frac{2.3\varepsilon_a}{\beta_a}} \quad (3)$$

Similarly the cathodic coefficient r_c is expressed as:

$$r_c = \frac{i_{c,\text{int}}}{i_{c,tot}} \quad (4)$$

where

The cathodic internal current density is given by $$i_{c,\text{int}} = i_{corr}\, e^{\frac{2.3\varepsilon_c}{\beta_a}} \quad (5)$$

and the cathodic total current density is given by $$i_{c,tot} = i_{corr}\, e^{\frac{2.3\varepsilon_c}{\beta_c}} \quad (6)$$

Substituting current densities in equation (1) and (4) results in the expressions

$$\varepsilon_a = \frac{\ln r_a}{2.3}\left(\frac{\beta_a\beta_c}{\beta_a - \beta_c}\right) \quad (7)$$

$$\varepsilon_c = \frac{\ln r_c}{2.3}\left(\frac{\beta_a\beta_c}{\beta_c - \beta_a}\right) \quad (8)$$

Which are the overpotentials for a given r ratio. It is easy to observe that $\varepsilon_a = -\varepsilon_c$ if $r_a = r_c$.

RESULTS

In this case it could be reasonable to accept that the internal current is negligible when it becomes one hundred times smaller than the corresponding total current, in other words r =1/100. On the other hand the Tafel slopes obtained in part II are β_c = -512 mv_/ decade and β_a = 176 mv / decade (1decade = 1cycle). By substituting these values in equation 7 and 8 the following OPNIC values are obtained:

$$\varepsilon_a = 262\,mv \quad and \quad \varepsilon_c = -262\,mv$$

This overpotential is very close to the practical value of - 273 mv given for cathodic protection.

Equations (2) and (5) give the corresponding negligible internal current densities using the experimental result i_{corr} = 19 μA/cm^2 obtained in Part II.

$$i_{a,\text{int}} = 5{,}86\,\mu A/cm^2 \quad and \quad i_{c,\text{int}} = 0.62\,\mu A/cm^2$$

Figure 2 shows the complete polarization diagram including the anodic and cathodic OPNIC and NIC values, which are the coordinates of the terminal points of the polarization lines.

REFERENCES:

1. Umaña, Carlos E.: Galvanostatic Polarization Curves for Teaching Purposes, NASA/ CP-1999-209549, National Educators' Workshop: Update 98, 1999.
2. Umaña, Carlos E.: Galvanostatic Polarization Curves for Teaching Purposes Part II, NASA/ CP-2000-210325), National Educators' Workshop: Update 99, 2000
3. Jones, Denny A.: Analysis of Cathodic Protection Criteria, Corrosion, Vol. 28, N°11, November 1972.
4. Jones, Denny A.: Principles and Prevention of Corrosion, Second edition, Prentice Hall, Inc., 1996.

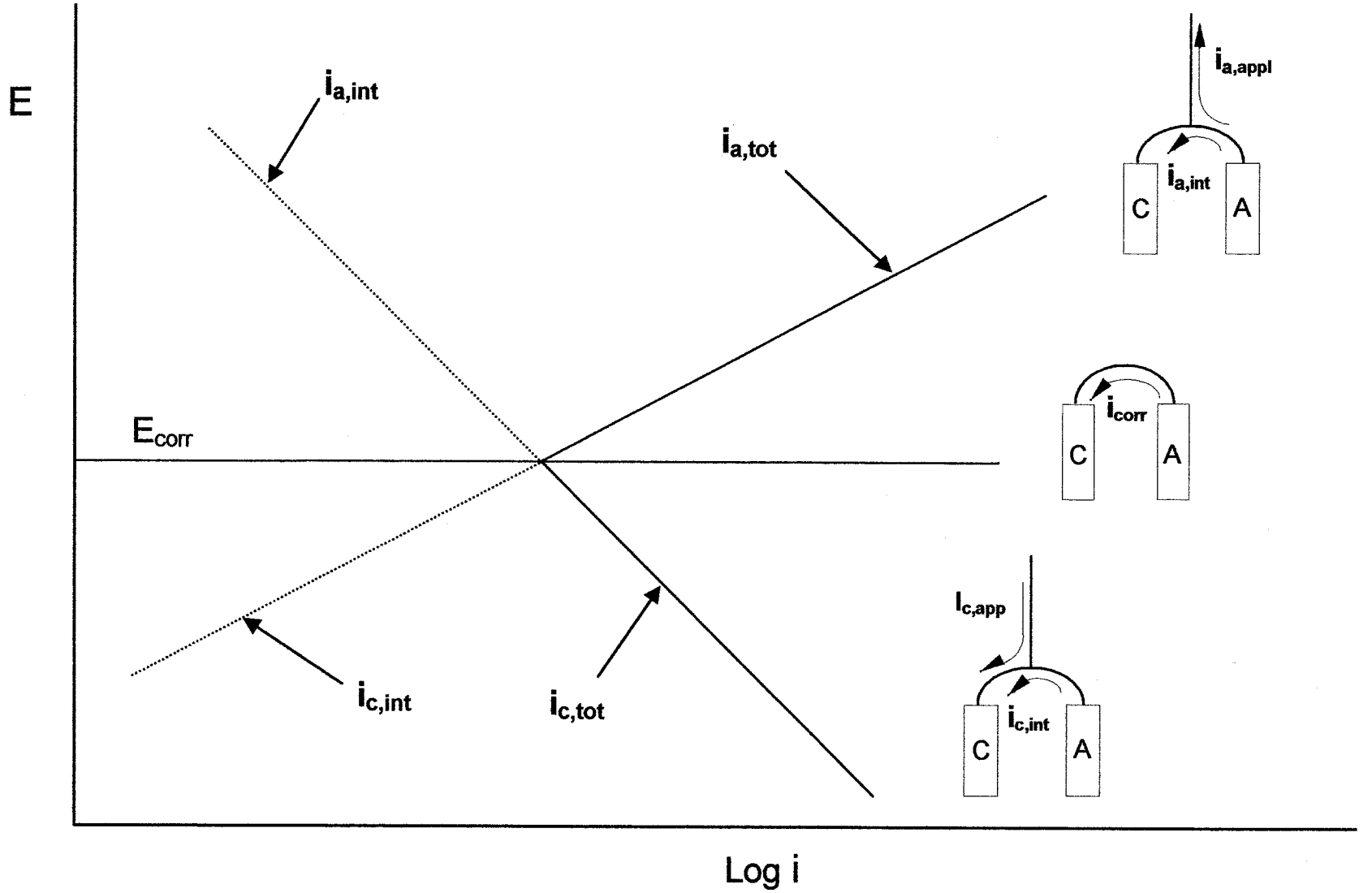


Figure 1. Schematic polarization diagram and working electrode at corrosion potential and anodic and cathodic overpotentials.

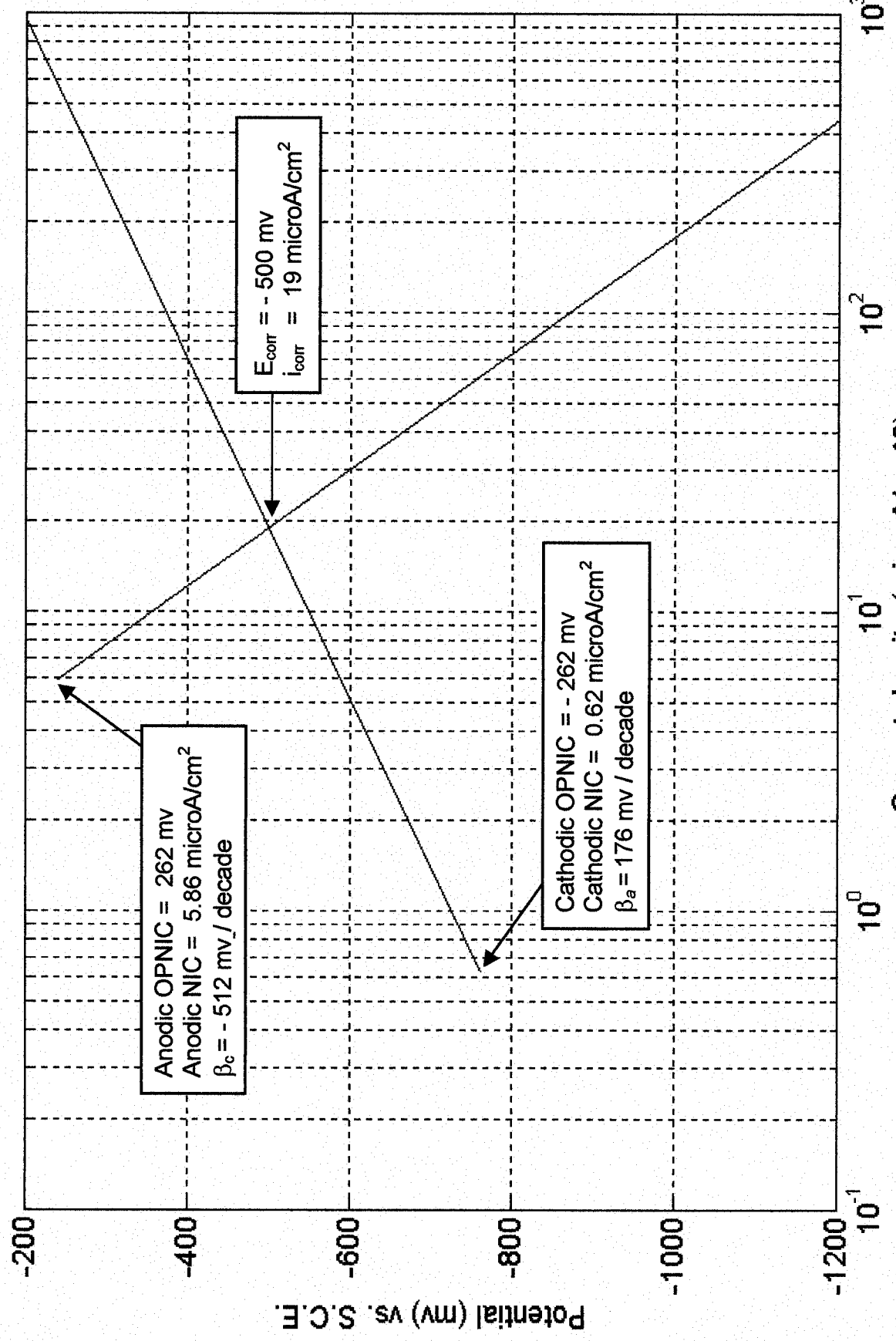


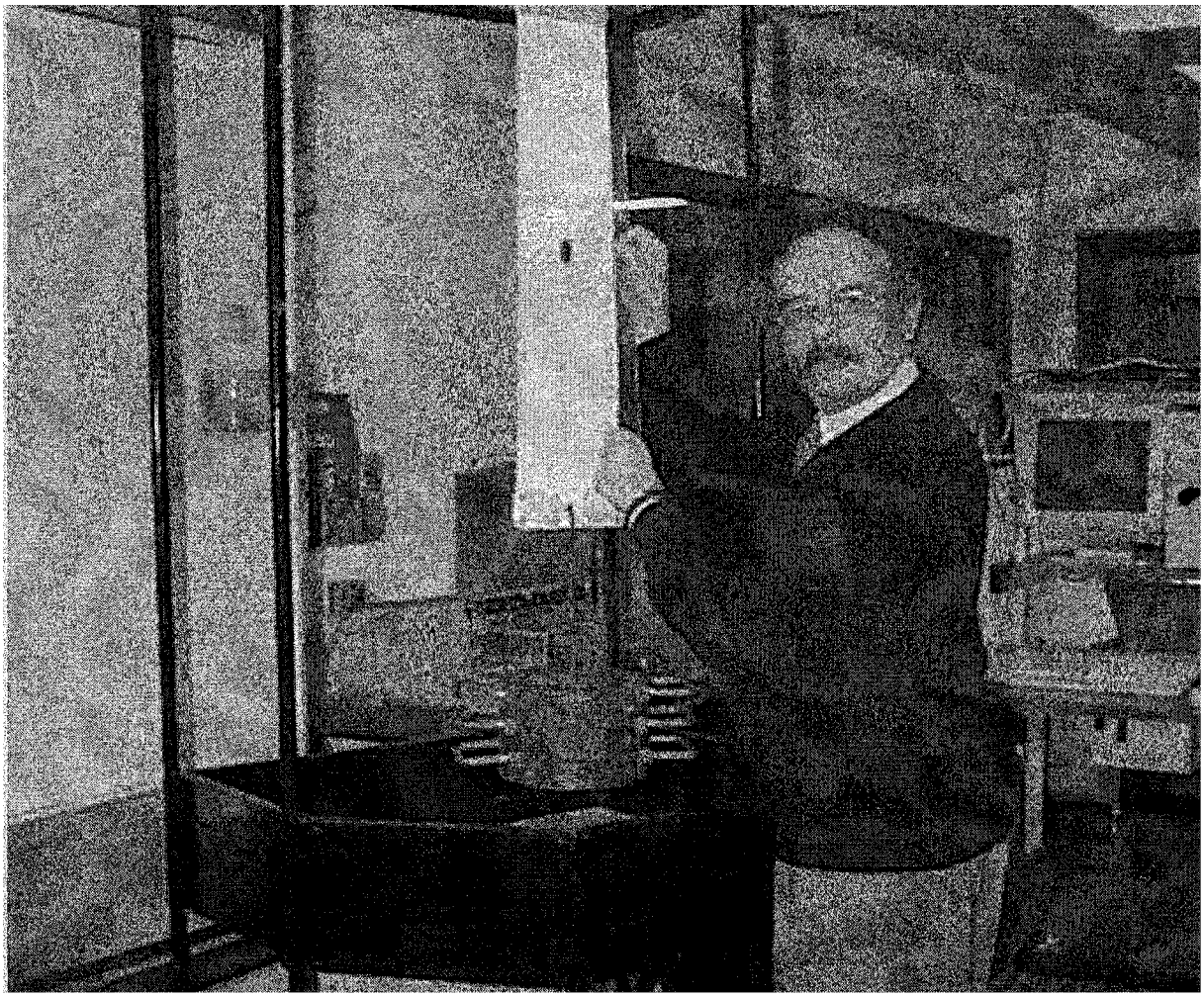
Figure 2. Polarization diagram for mild steel in a deaerated sodium chloride solution (20g/liter).

STRESS CONCENTRATION EFFECTS IN A THIN SHEET

Aaron S. Blicblau

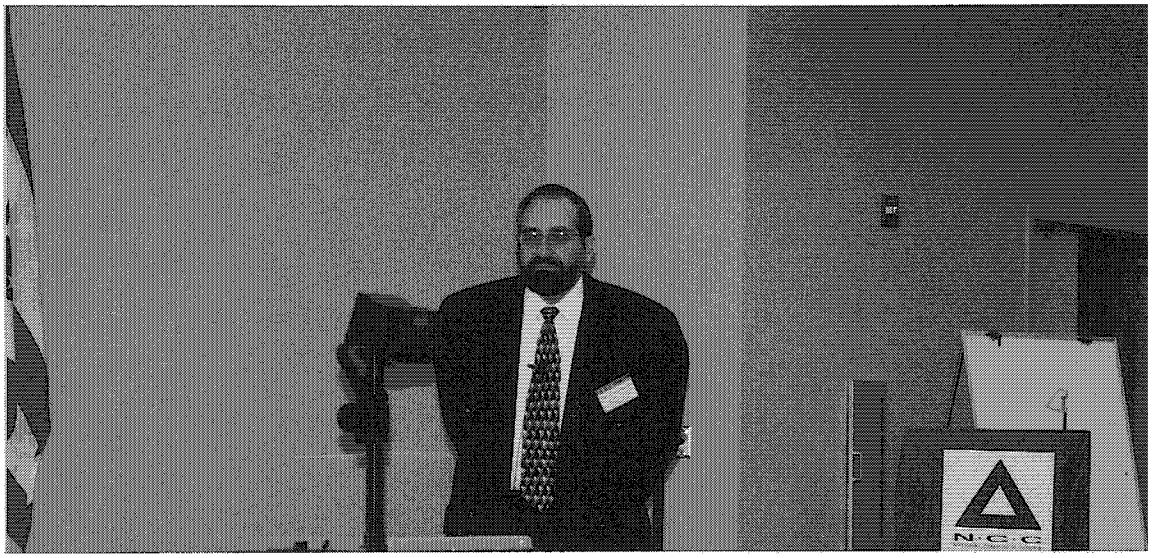
Senior Lecturer, Materials Engineering
School of Engineering and Science
Swinburne University of Technology
P. O. Box 218 Hawthorn
Victoria, Australia 3122

Telephone:
e-mail ABlicblau@groupwise.swin.edu.au



Aaron S. Blicblau

PRESENTED BY Harvey Abramowitz



Stress Concentration Effects in a Thin Sheet

Aaron S. Blicblau
Swinburne University of Technology
Hawthorn, Victoria,
Australia, 3122

Keywords: Stress concentration, thin sheet, round hole, geometry factor

Prerequisite Knowledge: Basic knowledge of linear elastic stress and strain, using Hooke's law. Conversion of deformation measurement to strain values, conversion of load data to stress values.

Objective: To demonstrate the effect of a hole on the stress concentration in a sheet of rubber.

Equipment and Materials:

1. One rubber sheet approximately 450mm x 200mm x 6 mm with a 30 mm round hole in the centre.
   On the rubber sheet (see Figure 1) is a square grid with ruled vertical and horizontal lines, one centimetre apart, centred on the round hole. This grid is four cm high and 18 cm wide.
   Near the top of the rubber sheet is a ruled square with sides 10 cm. with no holes.
2. Four individual weights each of 100 kN.
3. One metal frame from which to hang the rubber sheet.
4. One centimetre-millimetre graduated ruler.

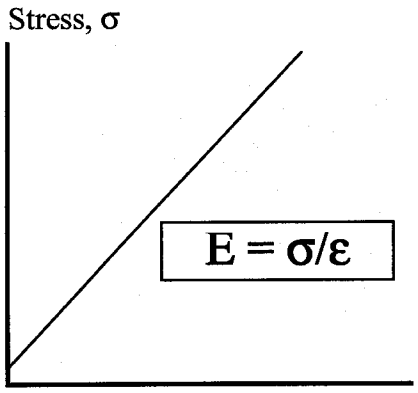
Introduction

In most engineering designs elastic properties of materials form the basis of design. These properties include stress (load/area), Young's modulus (stress/strain), and Poisson's ratio (strain in horizontal direction divided by strain in vertical direction). In this experiment the elastic behaviour of materials and the effect of a discontinuity (a circular hole in a plate) are to be investigated. A rubber sheet is used, since the low elastic modulus of rubber compared with metals allows greater deformation for a given load; it should be noted that there is a significant difference between rubber and metals in that the stress-strain relationship for rubber may be non-linear in the elastic range.

Theory

The intensity of force or stress "σ" (sigma), is defined as the force acting on unit area - (i.e. it is the same as pressure). Because engineers are interested in initial shape, nominal or engineering stress (force divided by initial cross sectional area) rather than actual stress (force divided by actual cross sectional area) is considered because it is easier to measure.

Consider the rubber sheet for this experiment (Figure 1a). If a force acts on it, elongation of the sheet occurs. So that the original length of the sheet does not have to be specified each time, the fractional change,(change in original length/original length) in a dimension, or strain "ε" (epsilon) is commonly used, i.e. Force α extension (Hooke's Law) as shown schematically in Figure 2.



The constant of proportionality is the gradient of the graph, "E", which is called the elastic modulus or Young's modulus.

Therefore

$$E = \sigma/\varepsilon$$

Figure 2. Schematic representation of a typical stress strain curve.

Procedure *Part A*

Measure and record the cross sectional area of the **whole** rubber sheet for calculation of nominal stresses, i.e., width and thickness of the sheet.

For each measurement required, **fill** in the data in Table 1.

1. **Measure and record** the dimensions of the top ruled square on the surface of the rubber sheet (i.e. shown in Figure 1b and is the ruled square away from the central hole). Note these are the *original dimensions* of the rubber square in the X and Y directions.
2. **Load** the sheet with 100 N, 200 N, 300 N and 400 N, one load at a time.
3. For each load, **measure and record** the change in length vertically (Y direction) and horizontally (X direction) produced in the **top square**, and write these values in Table 1.
4. **Calculate** the strains produced in the horizontal and vertical directions.
5. **Plot** σ_y as a function of the vertical strain (ε_y) and horizontal strain (ε_x), on Figure 3.

Report - *Part A.*

The cross sectional area of the rubber sheet perpendicular to Y axis:
A (cross section area) = (width x thickness) = 0.5mm x 150mm = 750 (mm^2)

Table 1. Measurements and calculations of strain and stress in the square section.

Applied Load	Y Vertical mm	X Horizontal mm	δ_y Change in Y dimension	δ_x Change in X dimension	ε_y (strain)	ε_x (strain)	σ_y (stress MPa)
0 N	100	100	0	0	0	0	0
100 N	105	97	5	3	0.05	0.03	0.13
200 N	110	95	10	5	0.10	0.05	0.26
300 N	118	93	18	7	0.18	0.07	0.4
400 N	125	90	25	10	0.25	0.10	0.53

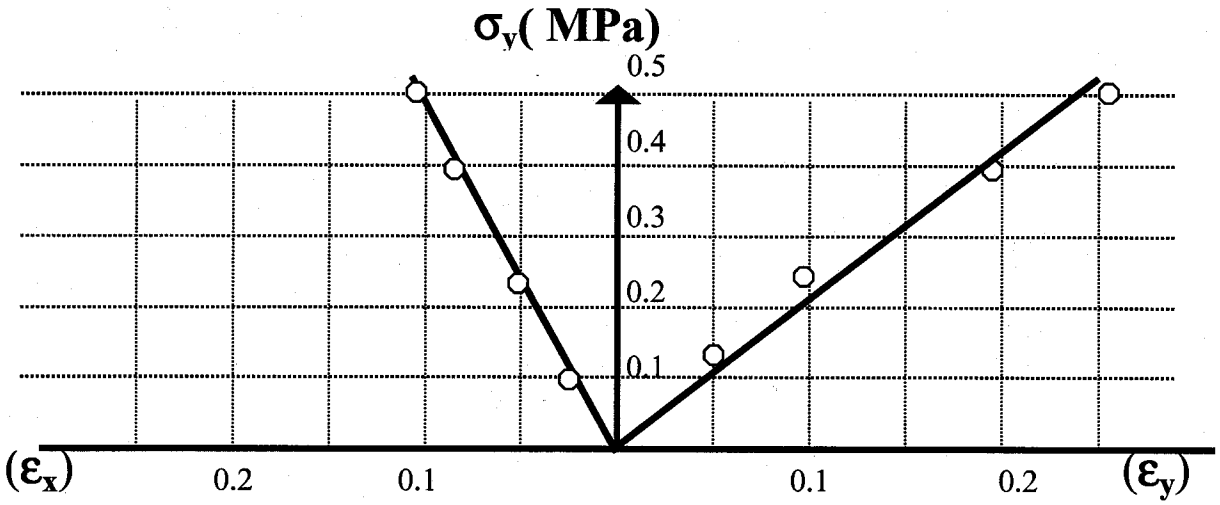


Figure 3. Stress σ_y as a function of the vertical strain (ε_y) and horizontal strain (ε_x).

Procedure *Part B*

On the rubber sheet, surrounding the hole, a rectangle containing 1 cm **square grids** has been ruled. This is to enable the strain to be determined at various positions away from the hole (see Figure 1b).

For each measurement required, **fill** in the data in Table 2.

1. For a load of **300 N, measure** and **record** in Table 2 the change in **vertical** distances between adjacent points on the grid around the hole between **a** and **b** (i.e. between points 1 and 1*, 2 and 2*, 3 and 3*, 4 and 4*, 5 and 5* 6 and 6* and 7 and 7*, as shown in Figures 1b and 3).
2. Using the results from part A in Table 1, **calculate E**, the MODULUS at 300N.
3. **Calculate** the strains at each position.
4. **Calculate** the stress at each position.
5. **Plot a graph** of stresses in the Y direction σ_y versus horizontal position (**X-X***) measured on the rubber sheet containing the hole, on Figure 4.

Report - *Part B.*

The **modulus** at 300N, is: **E = σ_y/ε_y (at 300 N) = 0.4/0.18=2.22 MPa**

Table 2 Measurements and stresses at various positions away from the hole on the rubber sheet.

Item	Position of Measurement						
	1-1*	2-2*	3-3*	4-4*	5-5*	6-6*	7-7*
Initial distance (y_o) between points (at 0 N)	20	20	20	20	20	20	20
Final distance (y_u) between points (at 300 N)	32	28	26.5	26	25	25	25
strain $\varepsilon_y = \frac{y_{u\ at 300N} - y_{o\ at\ 0N}}{y_{o\ at\ 0N}}$	0.6	0.4	0.325	0.3	0.25	0.25	0.225
stress $\sigma_y = E\varepsilon_y$	1.33	0.88	0.73	0.66	0.55	0.55	0.5

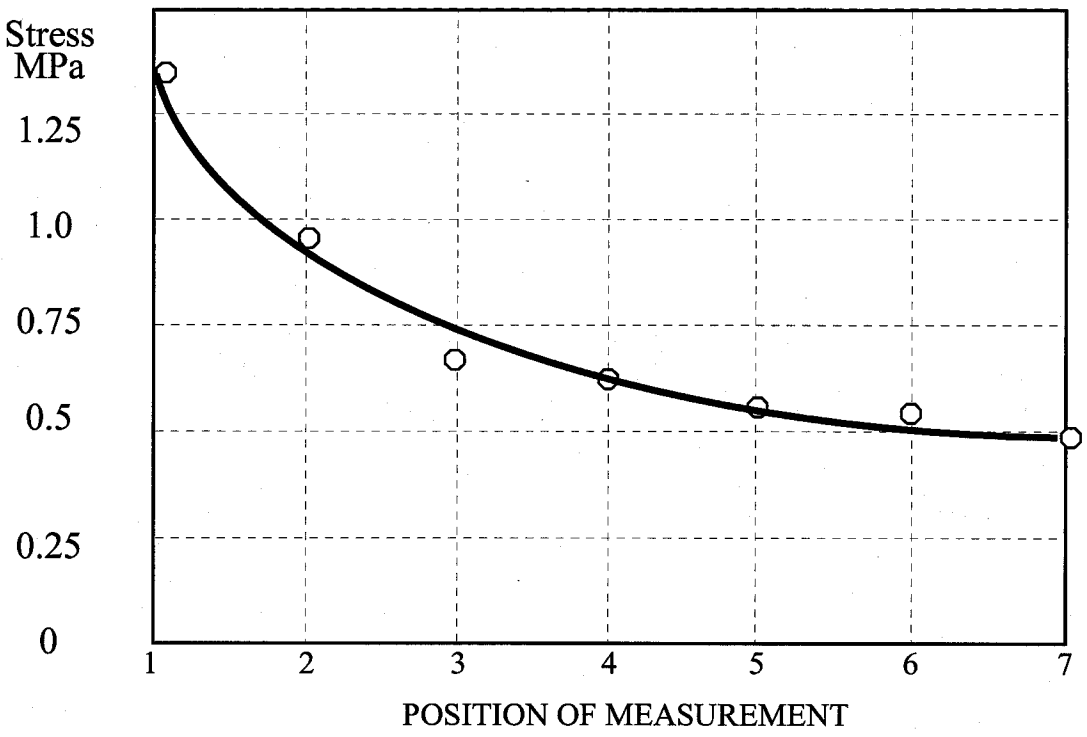


Figure 4. Stress at various horizontal positions away from the hole.

1. **Sketch below** (on Figure 5) the position in the rubber grid subjected to the ***greatest*** tensile stress. Mark this position as "**G**".
2. **Sketch below** (on Figure 5) the position in the rubber grid subjected to the ***least*** tensile stress. Mark this position as "**L**".
3. **Sketch below** (on Figure 5) the position subjected to the greatest ***compressive*** stress. Mark this position as "**C**".

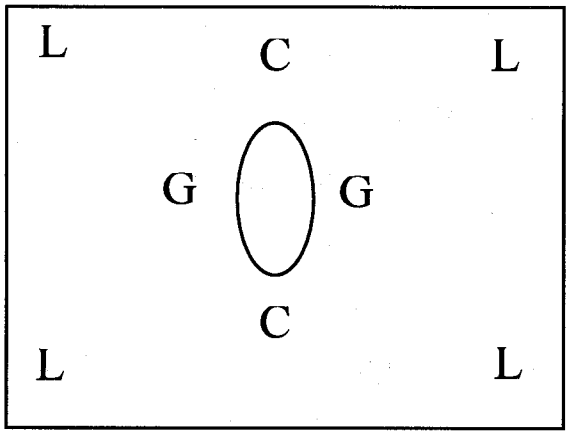


Figure 5. Positions on the rubber grid subjected to the greatest(G) and least(L) tensile stress and the greatest compressive (C) stress at a load of 300 N.

The **ratio of stresses,** and thus the stress concentration factor K_t is given algebraically as (Callister, 2000, p192):

$$K_t = \frac{\sigma_m}{\sigma_o} = 2\left(\frac{a}{\rho_t}\right)^{1/2}$$

where:

K_t is the stress concentration factor
σ_m is the maximum stress at the crack tip
σ_o is the magnitude of the nominal applied stress
a is the represents the length of a surface crack
ρ_t is the radius of curvature of the crack tip

Note that a and ρ_t are difficult to measure experimentally, so that K_t is **evaluated numerically** from the stresses calculated in Table 2 as:

$$K_t = \frac{\sigma_m}{\sigma_o} \qquad \text{i.e. } 1.33/0.5 = 2.66$$

List three common stress concentrators:

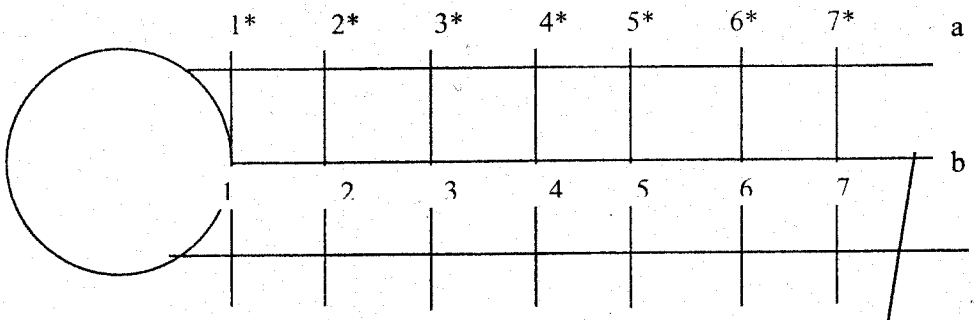
holes, flaws, and cracks or corners

References:

Callister,W.D.Jr, Materials Science and Engineering, Wiley, NY, 2000, 5th ed. pp.191-193.

Biography:

Aaron Blicblau received his B.E.(Hons) in Materials Engineering from Monash University, Australia in 1974. He then pursued postgraduate studies at the University of New South Wales in the area of fracture mechanics of natural composite materials. During 1993 he was a Visiting Scientist in the Department of Education in Science and Technology at the Technion, Israel Institute of Technology. Aaron is currently a Senior lecturer in the area of materials engineering and has most recently been coordinator of final year engineering projects for mechanical and manufacturing engineering students. *Correspondence:* Swinburne University of Technology, School of Engineering and Science, PO Box 218, Hawthorn, Victoria, Australia 3122.



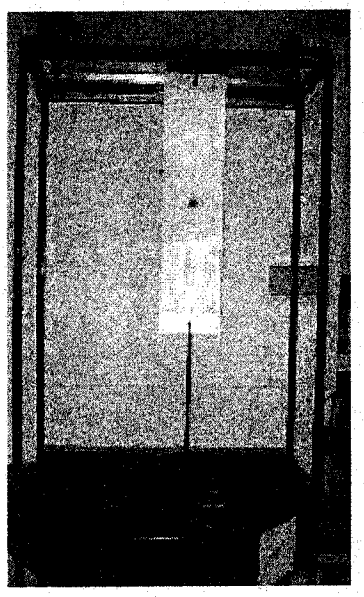


Figure 1a. Experimental set-up showing suspended rubber sheet with central hole and upper ruled square.

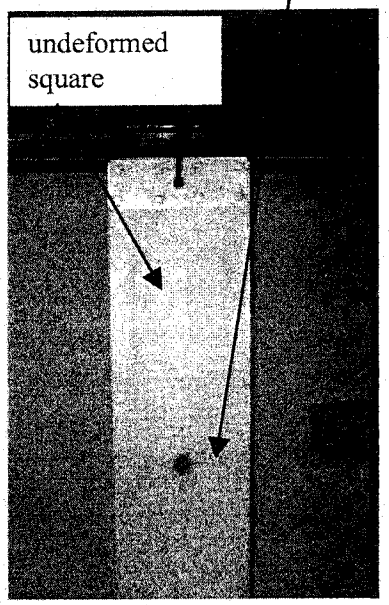


Figure 1b. Close-up of rubber sheet showing top square section and grid surrounding central hole.

Figure 3.Measuring the extension of the gridlines in the vertical direction.

CURRENT AND FUTURE USE OF STRUCTURAL AUTOMOTIVE COMPOSITE MATERIALS

Tom Dearlove

and

Ed Hagerman

GM R&D Center
MC: 480-106-316
30500 Mound Road
Warren, Michigan 48090-9055

Telephone: 810-986-1267
e-mail thomas.j.dearlove@gm.com

CURRENT AND FUTURE USE OF STRUCTURAL AUTOMOTIVE COMPOSITE MATERIALS

Tom Dearlove

Ed Hagerman

AUTOMOTIVE COMPOSITES CONSORTIUM MATERIALS GROUP

November 1, 2000

1906 New York Auto Show

Auto Body Materials	%
• Wood	64
• Aluminum	28
• Steel	5
• Wood and Metal	3

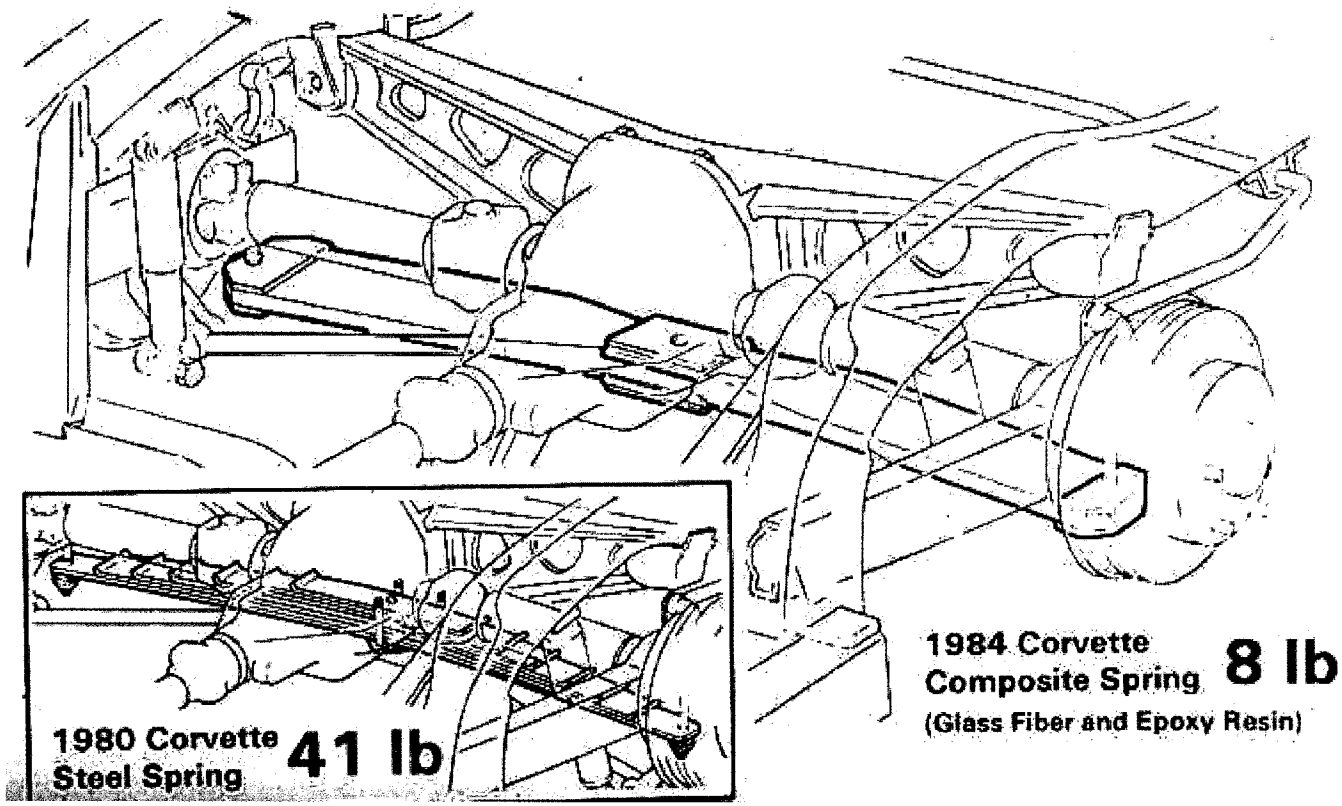
Henry Ford and 1941 Soya Oil based composite automobile.

Composite Body Production Automobiles
Corvette: 1953 to present

1953

2000

PLASTIC COMPOSITE LEAF SPRING SAVES 33 POUNDS



1984 Corvette Rear Leaf Spring
- First production *structural* composite application

CHOICES ABOUND

- ***Polymer Matrices***
- ***Reinforcement***
- ***Processes***
- ***Architectures***

Thermoplastic vs Thermoset

Thermoplastics

- Description
  - Melt, flow and cool polymer matrix to final shape
  - Remeltable
- Advantages
  - Directly recyclable with some loss of properties
  - Shorter cycle time
- Disadvantages
  - Dimensional stability at high temperatures
  - Paint offline

Examples: Nylon, PPS, PEEK

Thermosets

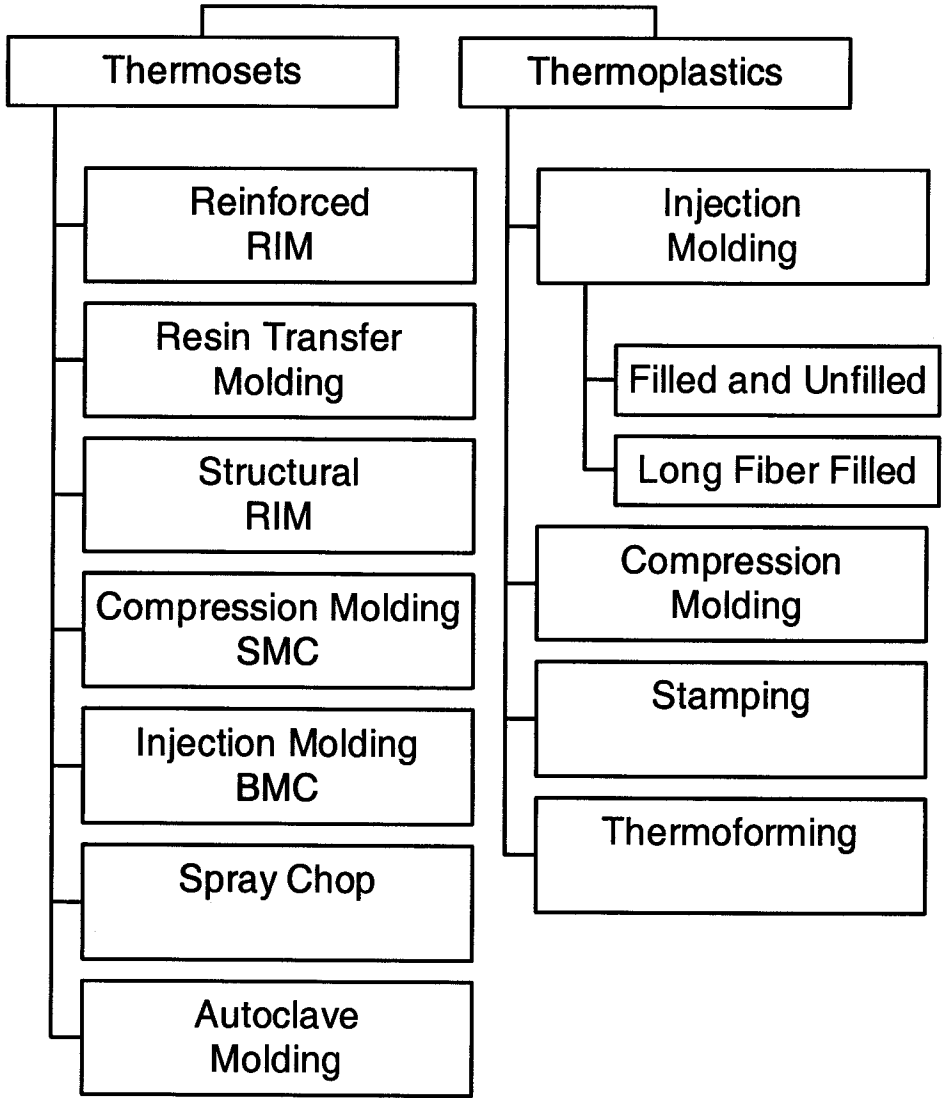
- Description
  - Mix and flow resin and curing agent
  - React to form polymer matrix with final shape
  - Crosslinked cannot be melted
- Advantages
  - Higher use temperature
  - Paint online with steel
- Disadvantages
  - Secondary recycling

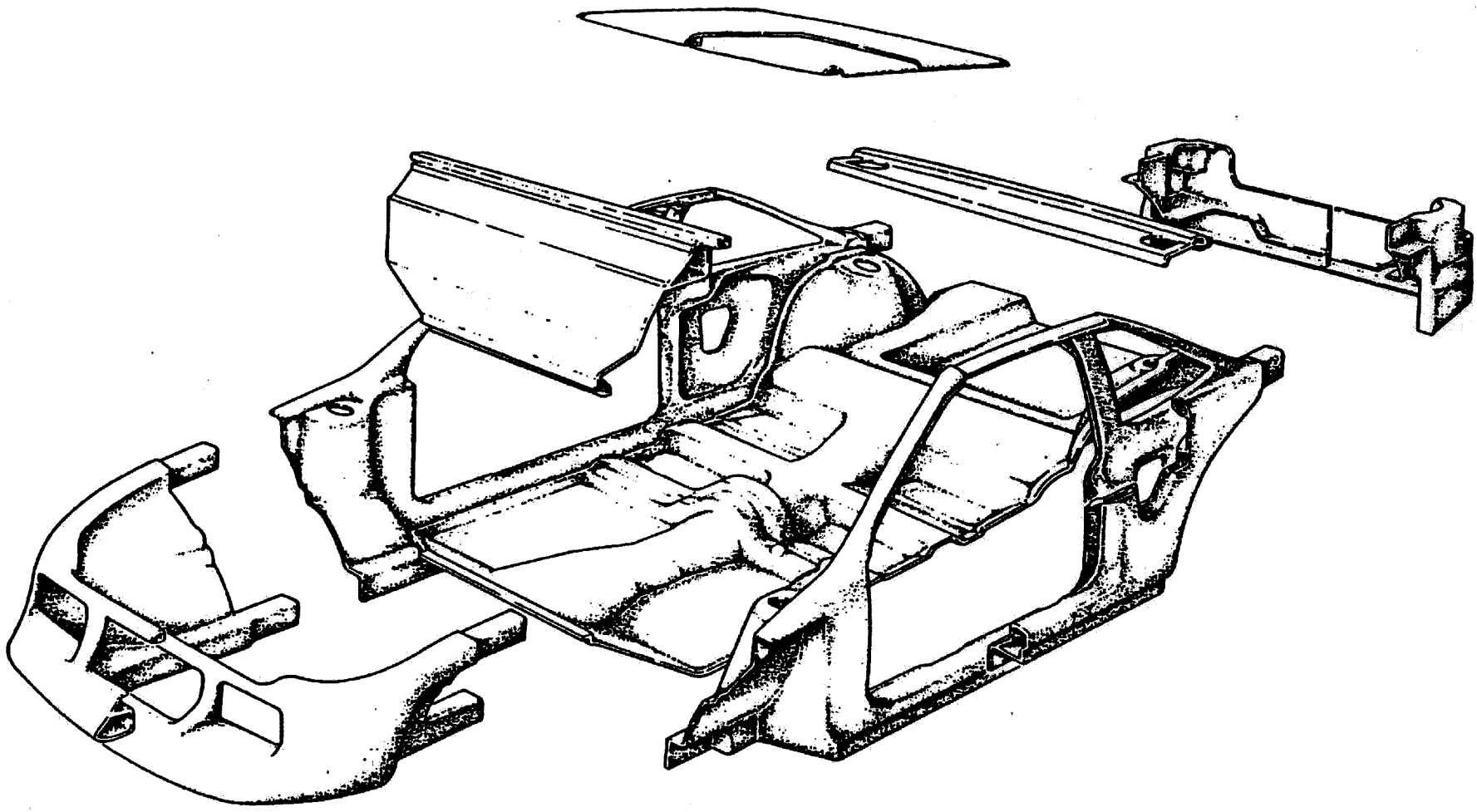
Examples: RIM Urethane, Epoxies
Polyesters

Reinforcement Types

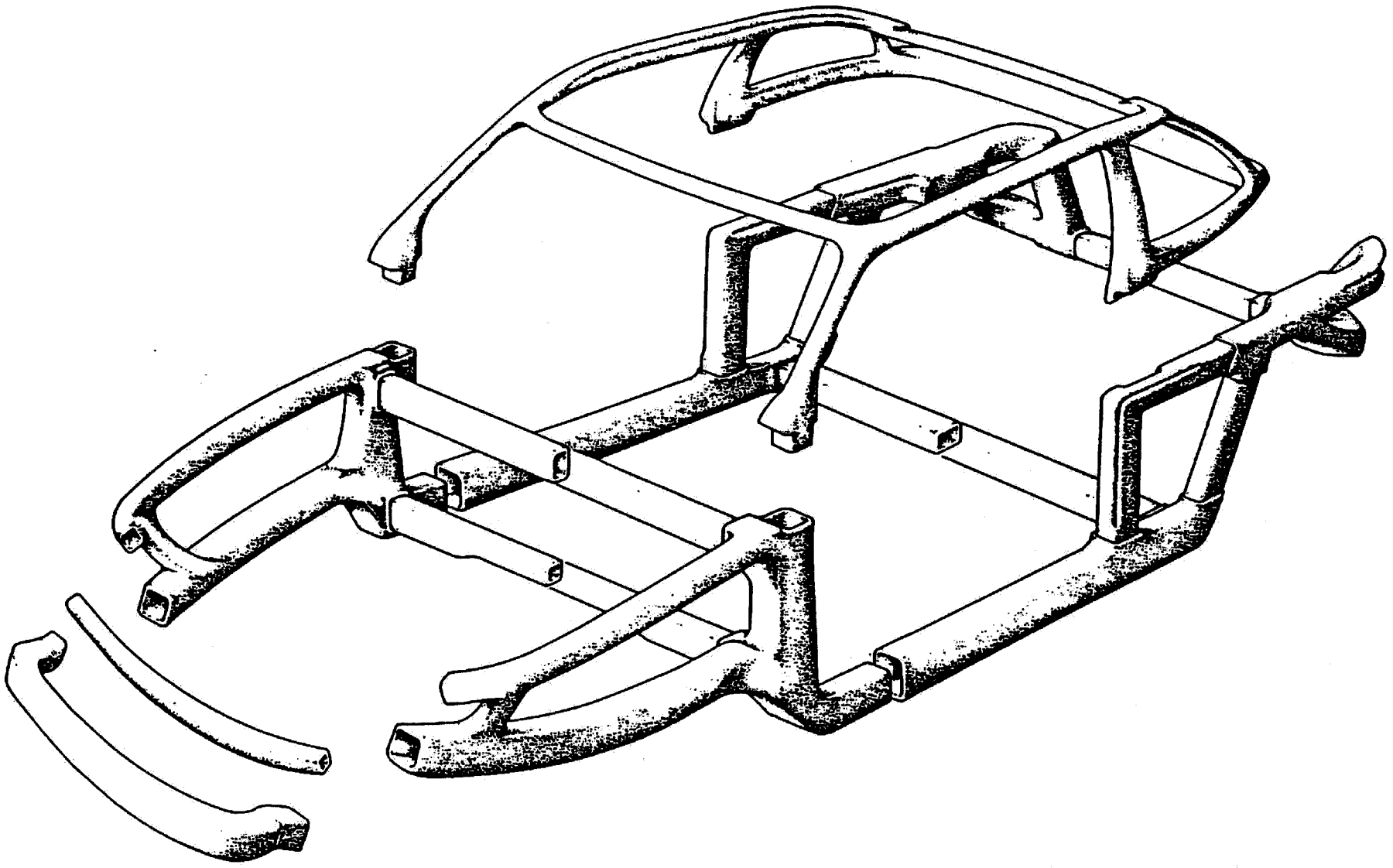
- Fillers (talc, calcium carbonate, clay, milled glass)
  - Used in all processes to raise modulus and decrease CLTE
- Chopped fibers
  - Injection molding
  - Compression molding
  - SRIM (Directed fiber preform)
- Continuous swirl mat
  - Thermoplastic stamping
  - Thermoset RTM and SRIM
- Unidirectional fiber and woven fabric
  - Maximize effectiveness of fiber
  - Thermoplastic stamping (commingled glass and plastic fibers)
  - Thermoset Autoclave Molding, RTM and SRIM

Polymer Composites Molding Processes





Unitized Body construction



Spaceframe construction

Monocoque construction

Automotive Requirements

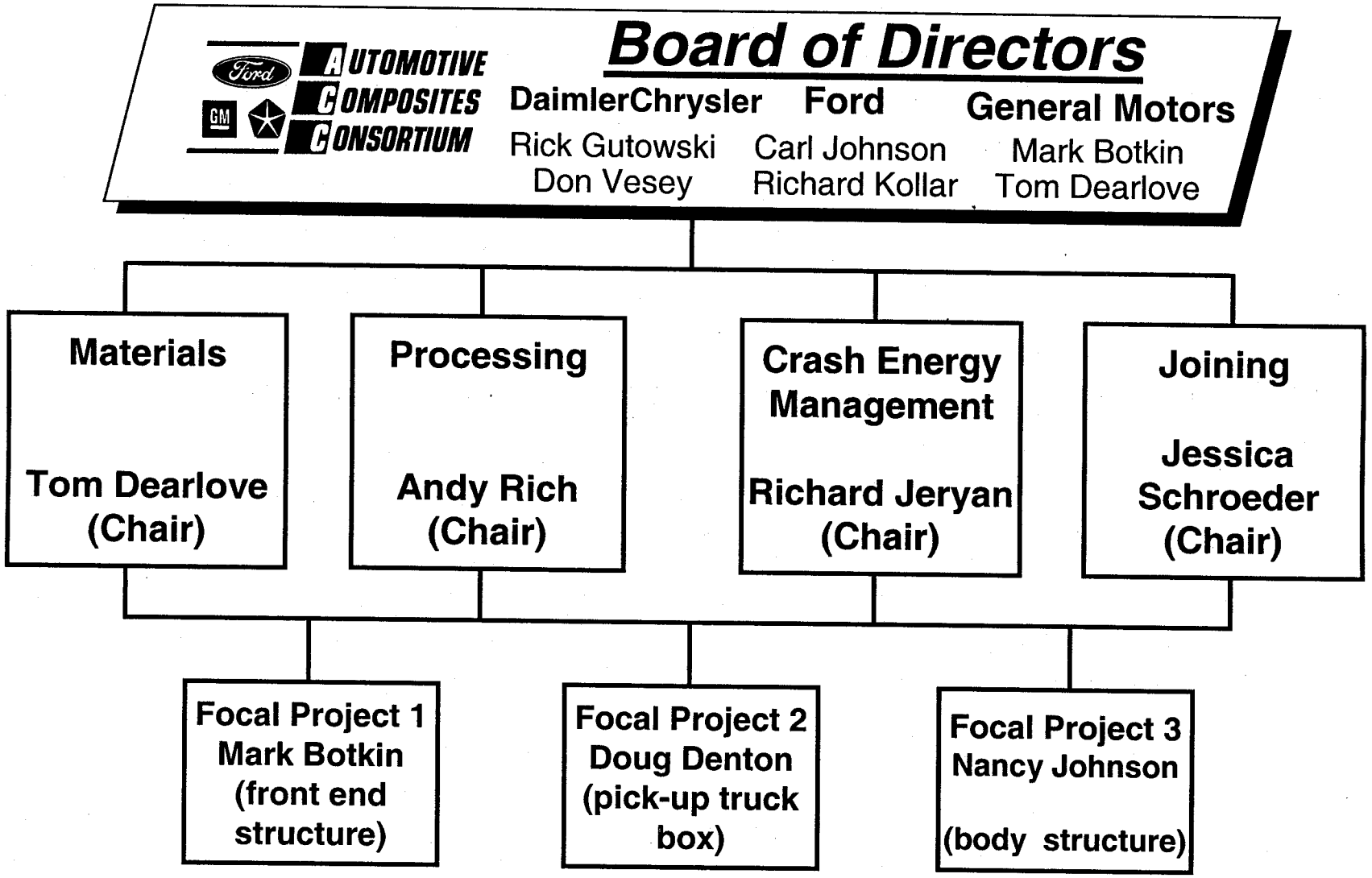
- **Low Cost**
- **High Volume**
- **Low Mass**

Optimized material usage and performance can only be achieved through modeling

AUTOMOTIVE COMPOSITES CONSORTIUM

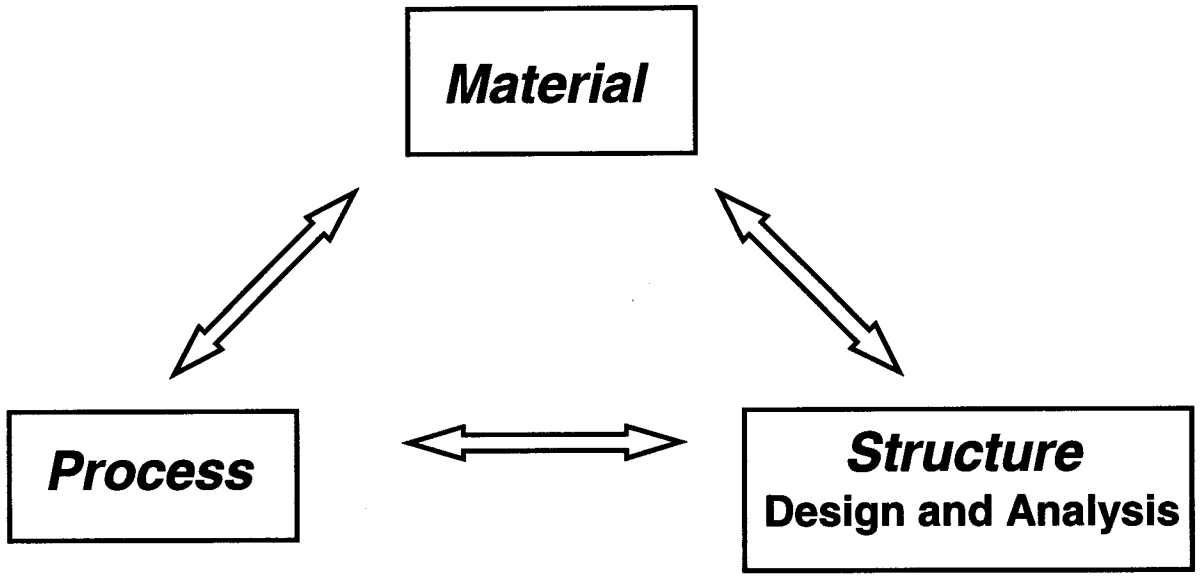
Mission

Develop structural polymer composite technology for automotive applications through cooperative, precompetitive, research programs. Pool technical and financial resources to accelerate technology development and enhance individual competitiveness.



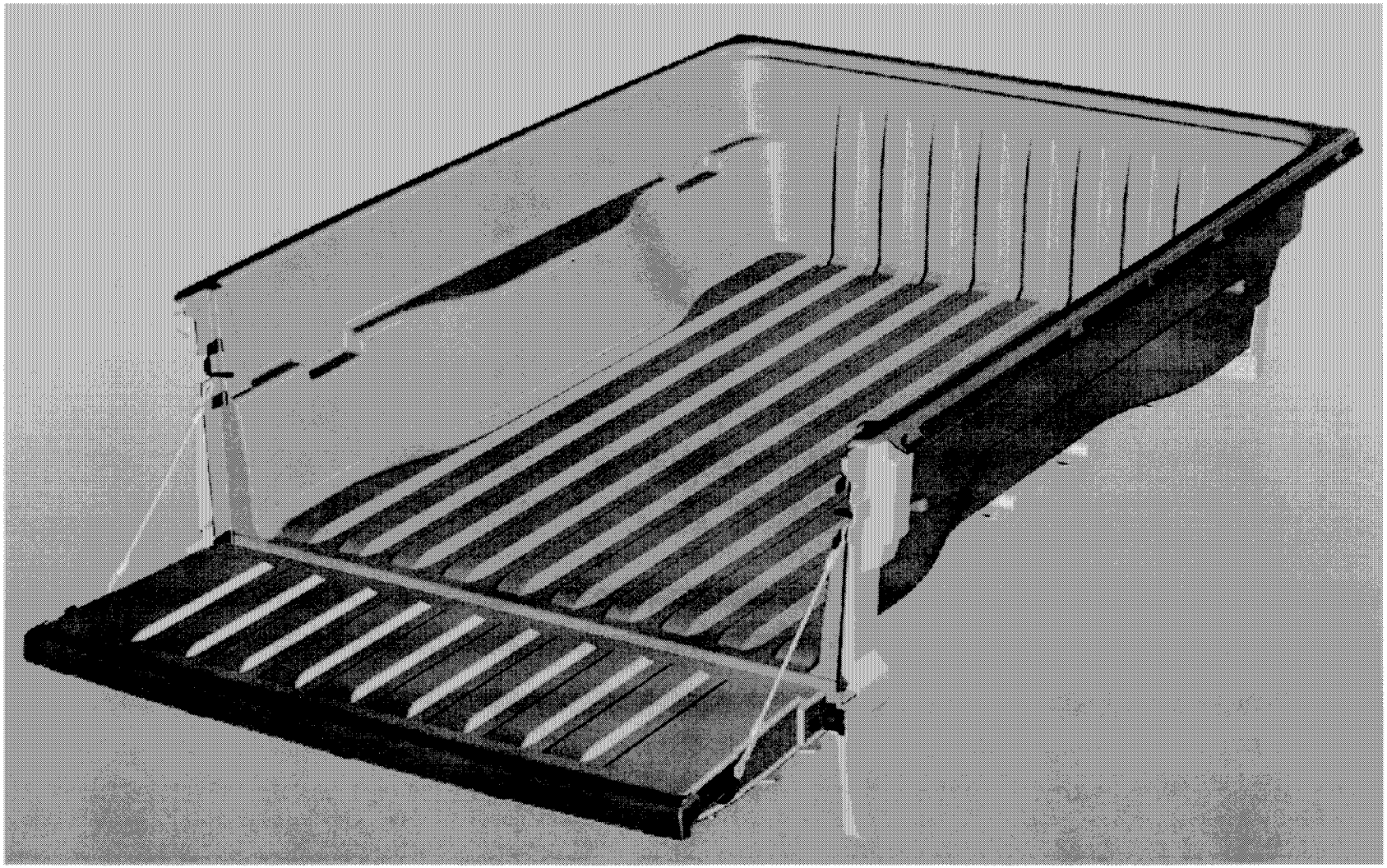
org_acc.ppt
4/99

PHILOSOPHY:
Decision Tree for Getting Started

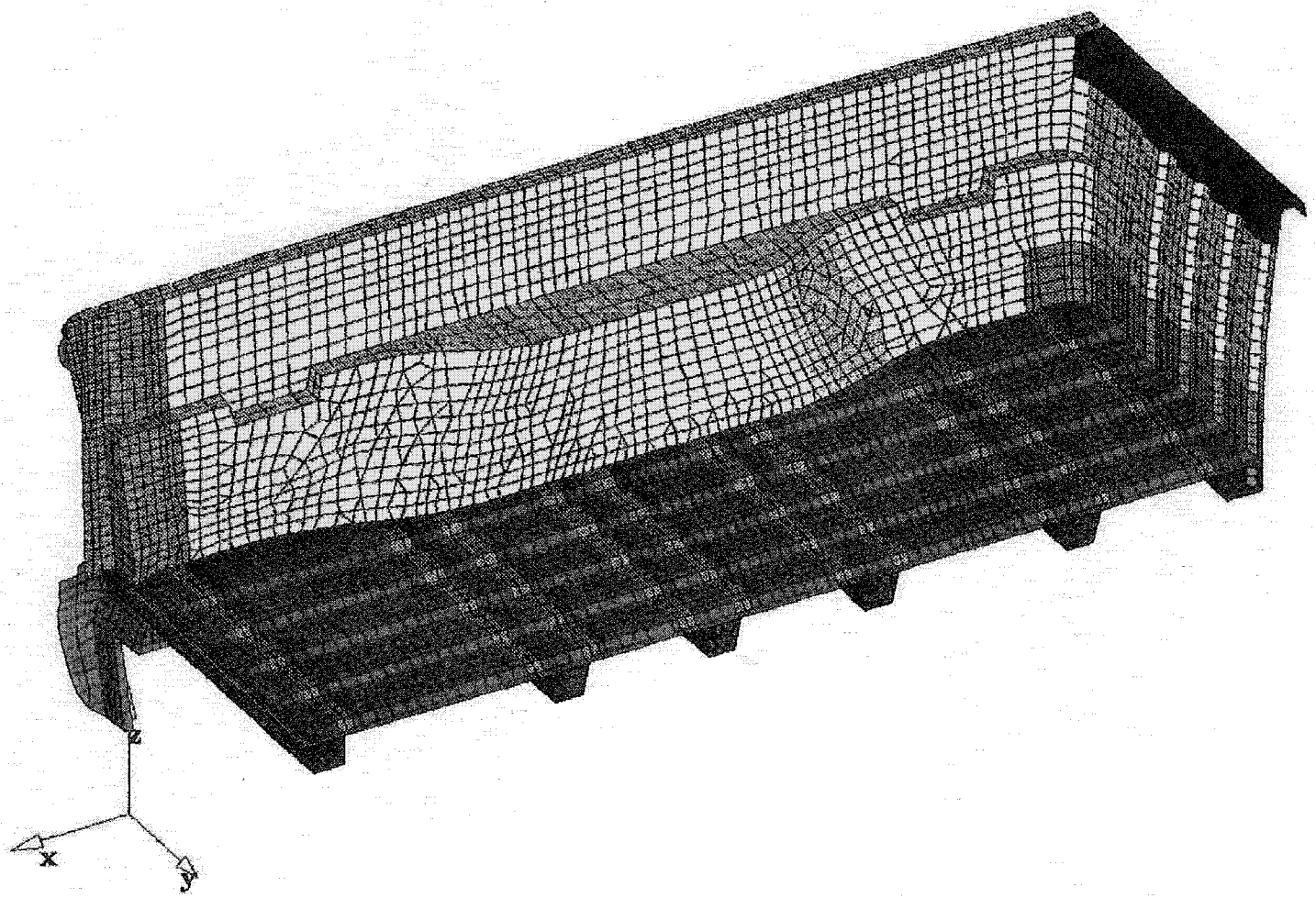


- **The structure (size, complexity and service requirements) will dictate what choices of material and process are most effective**
- **Development sequence is highly iterative**

ACC Composite Pickup Box
CAD Solid Model



ACC Composite Pickup Box - Finite Element Model



ACC Focal Project II / Composite Pickup Box

- Requirements -

Loadcase	Applied Load		Requirement
	N	Lbs	
Hoof # 1	2700	607	Stiffness > 3500 N/cm
Hoof # 2	2700	607	Stiffness > 3500 N/cm
Hoof # 3	2700	607	Stiffness > 3500 N/cm
Hoof # 4	2700	607	Stiffness > 3500 N/cm
Hoof # 5	2700	607	Stiffness > 3500 N/cm
Ultimate	30120	6772	Stiffness > 3500 N/cm
Front	3336	750	Deflection < 30 mm

ACC Focal Project II Material Properties
Altair Experiment 1

Property	Dow MM364 / Dir Fiber Composite	SMC R-50	Epoxy Adhesive
Tensile Modulus GPa	9.6	15.6	2.95
Poisson's Ratio	0.36	0.31	0.34
Shear Modulus GPa	3.6	5.9	1.04
Comp. Modulus GPa	11.2	15.9	2.95
Density g/cc	1.52	1.80	1.20
Maximum Stress			
Tension MPa	152	164	61
Compression MPa	188	225	61
Shear MPa	112	62	31

1. Composite at RT with 40 wt% reinforcement
2. SMC at RT with 50 wt% reinforcement
3. Adhesive at RT

ACC Focal Project II / Composite Pickup Box

Altair Experiment #1 (40% wt. Glass SRIM)
(50% wt. Glass SMC)

Loadcase	Applied Load		Requirement	Maximum Deflection		Stiffness	
	N	Lbs		mm	inch	N / cm	lbs. / inch
Hoof # 1	2700	607	Stiffness > 3500 N/cm	3.8	0.15	7110	4050
Hoof # 2	2700	607	Stiffness > 3500 N/cm	6.9	0.27	3910	2230
Hoof # 3	2700	607	Stiffness > 3500 N/cm	6.1	0.24	4430	2530
Hoof # 4	2700	607	Stiffness > 3500 N/cm	5.9	0.23	4430	2530
Hoof # 5	2700	607	Stiffness > 3500 N/cm	7.3	0.29	3700	2110
Ultimate	30120	6772	Stiffness > 3500 N/cm	13.6	0.54	22150	12610
Front	3336	750	Deflection < 30 mm	29.3	1.15	1140	650

Effect of Thickness on Stiffness

Automotive Designs are Stiffness Controlled

Higher composite modulus allows:

Thinner sections, lower weights, lower costs

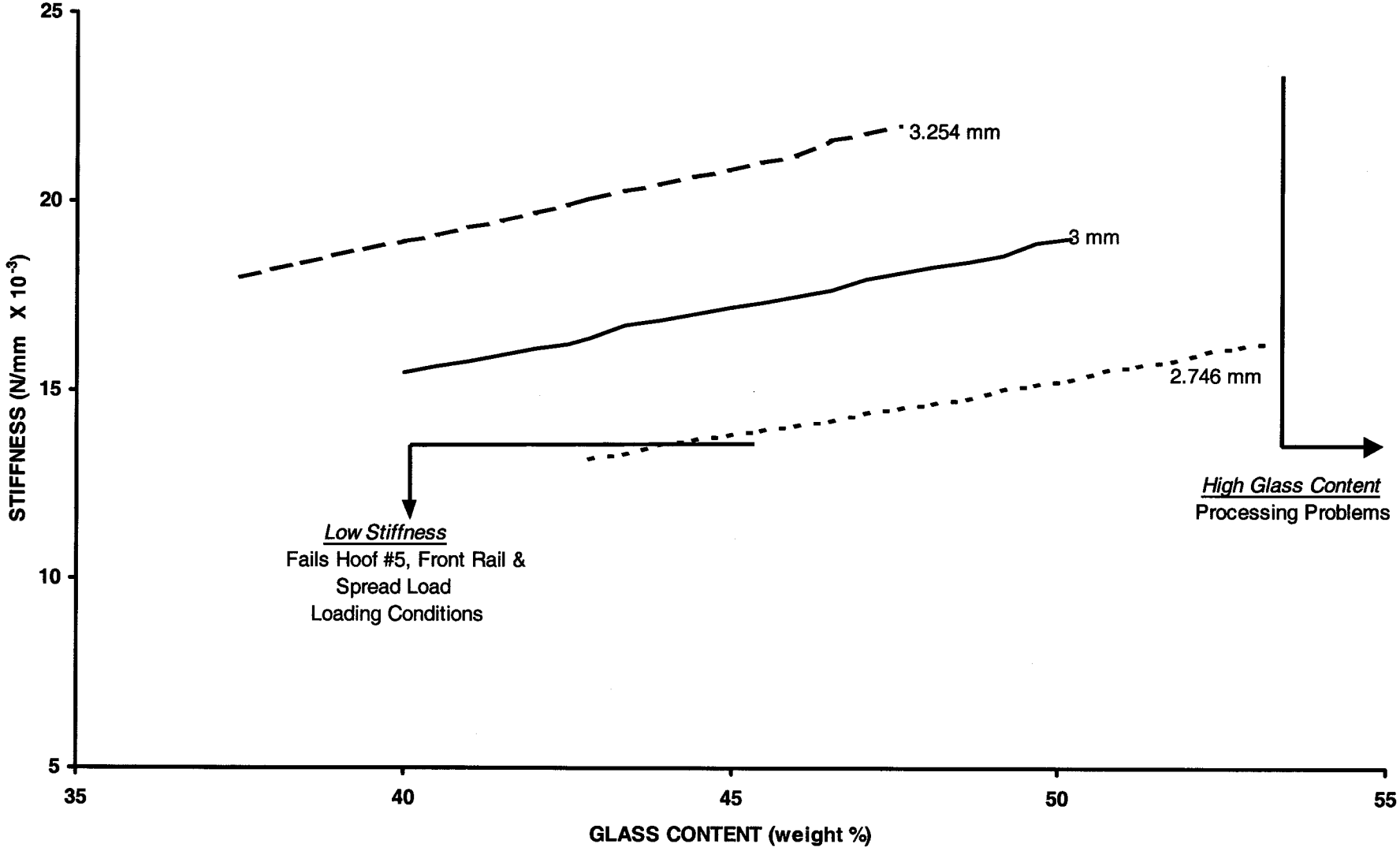
Stiffness ~ $1 / E t^x$

E = modulus

t = thickness

x = thickness power

STIFFNESS VS GLASS CONTENT and THICKNESS

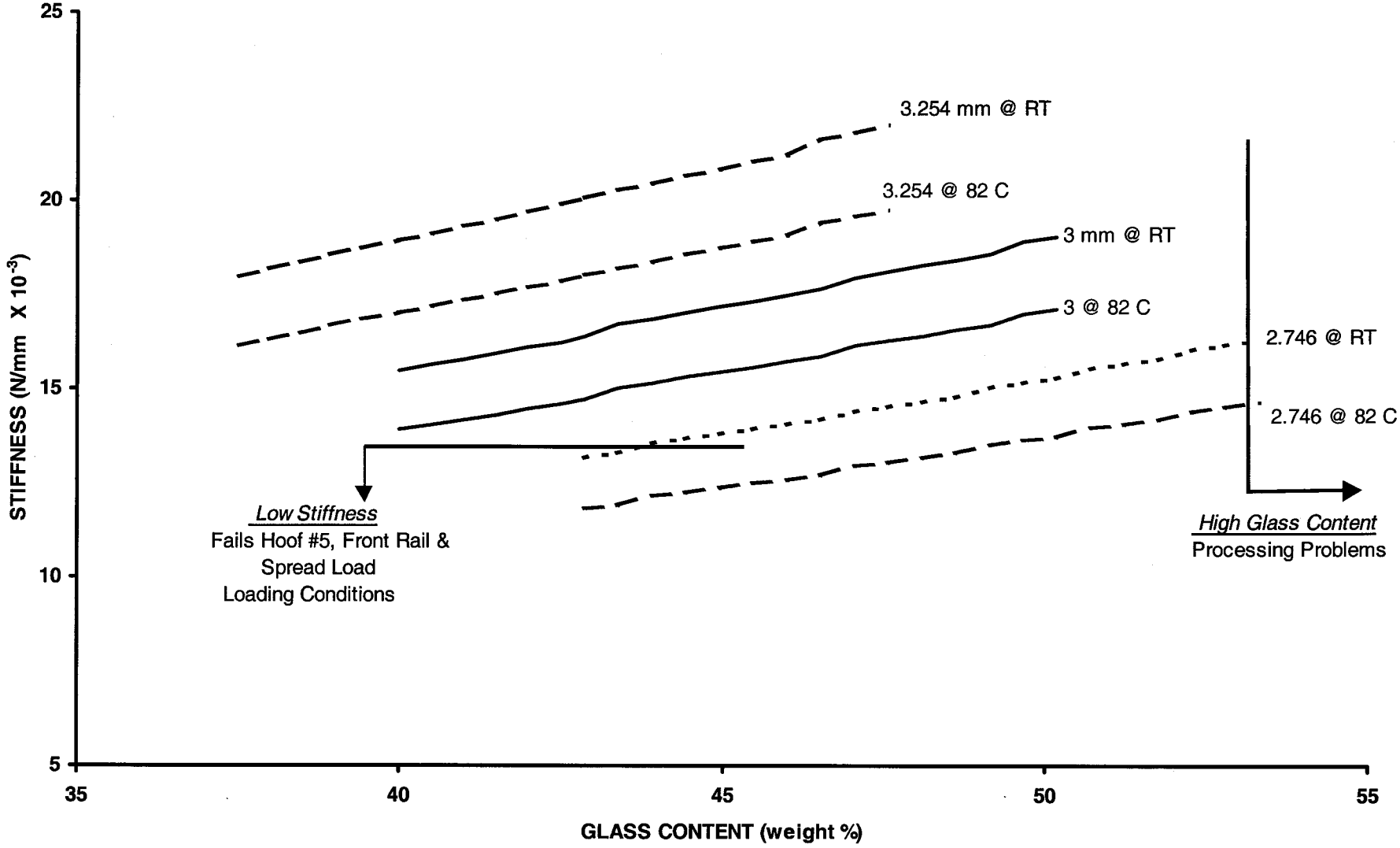


ACC Focal Project II Material Properties
Temperature & Statistics Effects
Dow Spectrim MM364 / Directed Fiber Material[1]

	-40° C			Room Temperature			82° C		
Glass wt.%	40	45	50	40	45	50	40	45	50
Tensile Modulus GPa	10.7	12.0	13.3	9.6	10.8	12.0	8.6	9.7	10.8
Poisson's Ratio	0.34	0.33	0.32	0.36	0.35	0.34	0.38	0.37	0.36
Shear Modulus GPa	3.8	4.1	4.7	3.6	4.0	4.5	3.4	3.9	4.3
Compression Modulus GPa	13.7	15.5	17.2	11.2	12.6	14.0	8.8	9.9	11.0
Density g/cc	--	--	--	1.52	1.57	1.63	--	--	--
Maximum Stresses									
Tension MPa	183	205	228	152	171	190	123	139	154
Compression MPa	274	308	344	188	211	235	107	120	133
Shear MPa	144	161	180	112	126	140	82	93	103

1 Data extrapolated and/or calculated from averages at other fiber contents and temperatures. Directed fiber and continuous strand mat data included

STIFFNESS VS GLASS CONTENT, THICKNESS and TEMPERATURE VARIATIONS



Conclusions from Analysis

- **Glass content must be controlled to 45 ± 5 weight per cent**
- **Thickness must be controlled 3 ± 0.254 mm**

Parts fail specific load cases if control is lost

SCREENING TESTS

Primary Testing

PHYSICAL

- FIBER CONTENT
- DENSITY

MECHANICAL @ Room Temperature

- TENSILE (0/90° Modulus, Strength, Fail Strain, Poisson's Ratio)
- COMPRESSION (0/90° Modulus, Strength, Fail Strain, Fail Energy)
- SHEAR (Modulus, Strength, Fail Strain)

THERMAL

- DMA
  - E' Curve (~ Young's Modulus Response)
  - E" Peak (Estimate of Tg)
  - T_{75} (Temp. at 75% Modulus Retention)

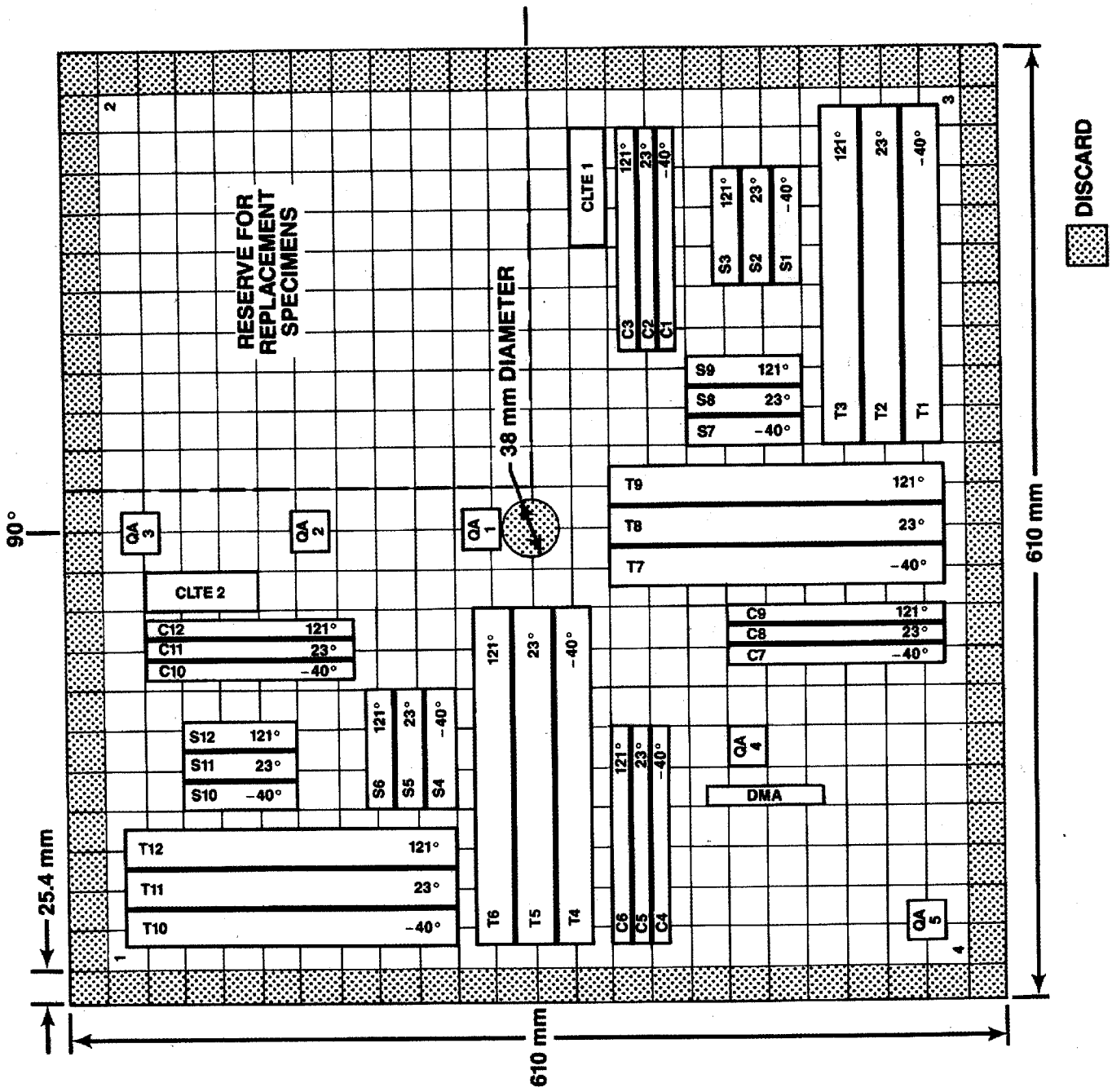
Secondary Testing

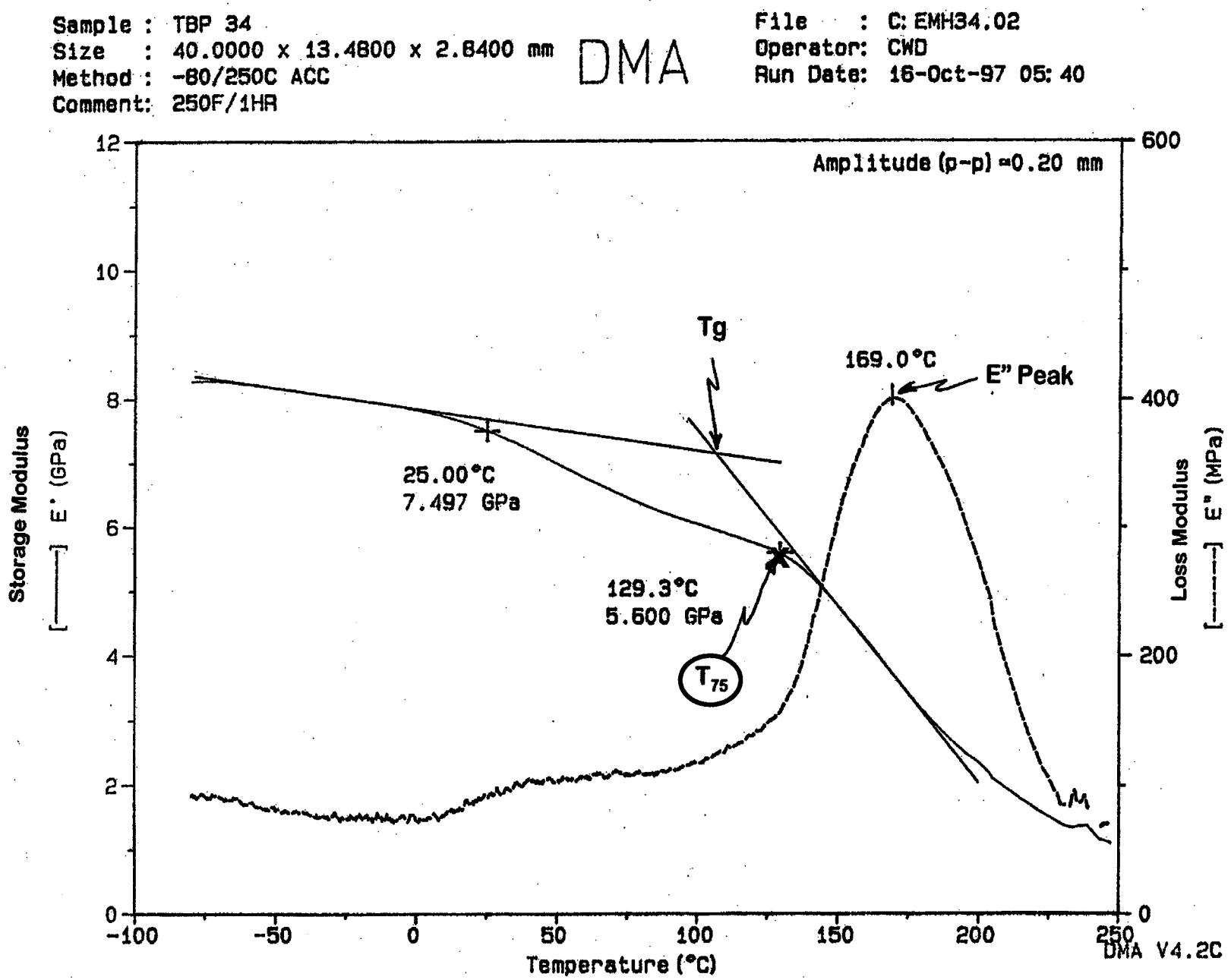
THERMAL

- DSC
  - Degree of cure
- CLTE
  - Three temperature ranges

ENVIRONMENTAL Humidity Aging 100F / 90%RH

- PHYSICAL (Moisture Uptake, Dimension Change)
- MECHANICAL
  - TENSILE (Modulus, Strength, Fail Strain)
  - COMPRESSION (Modulus, Strength, Fail Strain)


DISCARD
RESERVE FOR REPLACEMENT SPECIMENS
38 mm DIAMETER
CLTE 1
CLTE 2
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
S1
S2
S3
S4
S5
S6
S7
S8
S9
S10
S11
S12
T1
T2
T3
T4
T5
T6
T7
T8
T9
T10
T11
T12
121°
23°
-40°
QA 1
QA 2
QA 3
QA 4
QA 5
DMA
90°
25.4 mm
610 mm
610 mm


Sample : TBP 34
Size : 40.0000 x 13.4800 x 2.8400 mm
Method : -80/250C ACC
Comment: 250F/1HR
DMA
File : C:EMH34.02
Operator: CWD
Run Date: 16-Oct-97 05:40
Amplitude (p-p) =0.20 mm
Tg
169.0°C
E" Peak
25.00°C
7.497 GPa
129.3°C
5.600 GPa
T75
Storage Modulus
[——] E' (GPa)
Loss Modulus
[- - -] E" (MPa)
Temperature (°C)
DMA V4.2C

AUTOMOTIVE COMPOSITE MATERIAL PROPERTIES

RESIN	BAYER BAYDUR ***420 IMR Urea/Urethane***
REINFORCEMENT	Battice P4 ***OC RO7EX1 – Cray Valley - Chopped***
PROCESSING DATES	**October 2, 1997 - Troy Tool -Postcured**
FIBER VOL. (VOL% (WT %))	**28.9** (46.4)
SPECIFIC GRAVITY	**1.616**
CLTE (°C x E-6) (range 30-80°)	**16.9**
REF TEMP T_{75} (°C)	**118 std. dev. 7.5**
DATA ARCHIVE	**Bayer 420IMR/BatticeP4Cray**

TENSILE PROPERTIES

	TEMPERATURE (°C)	**-40**	**sd**	**25**	**sd**	**120**	**sd**
STRENGTH (MPa)	**0°**	193	12.4	167	8.9	125	11.1
	90°	193	21.9	175	18.4	130	13.5
	average	***193***	17.4	***171***	14.9	***127***	12.4
MODULUS (GPa)	**0°**	13.2	1.32	11.4	1.15	8.1	0.89
	90°	13.7	1.38	11.9	1.16	9.0	1.13
	average	***13.4***	1.35	***11.6***	1.15	***8.6***	1.09
FAIL STRAIN (%)	**0°**	2.23	0.407	1.88	0.242	1.87	0.216
	90°	2.22	0.264	1.91	0.177	1.74	0.243
	average	***2.23***	0.338	***1.89***	0.208	***1.81***	0.234
POISSON'S RATIO	**0°**	0.300	0.044	0.319	0.033	0.298	0.054
	90°	0.306	0.044	0.315	0.046	0.347	0.048
	average	***0.303***	0.043	***0.317***	0.039	***0.321***	0.056

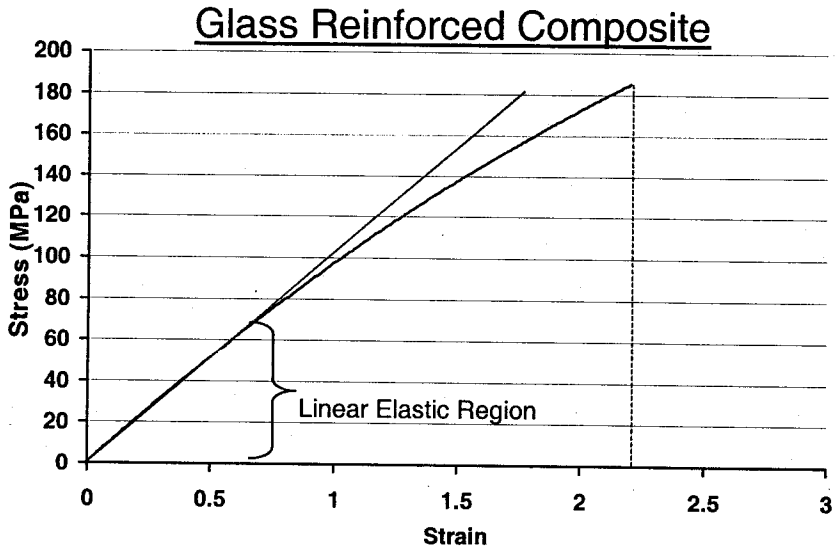
COMPRESSION PROPERTIES

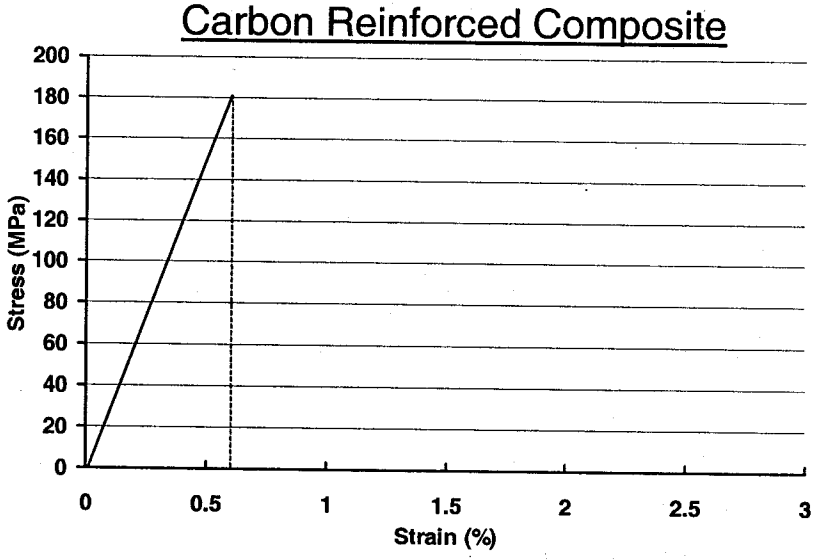
	TEMPERATURE (°C)	**-40**	**sd**	**25**	**sd**	**120**	**Sd**
STRENGTH (MPa)	**0°**	304	28.1	213	19.8	101	8.7
	90°	315	20.1	222	27.1	100	9.8
	average	***309***	24.5	***218***	23.7	***100***	9.1
MODULUS (GPa)	**0°**	12.9	0.84	11.7	1.17	8.6	0.47
	90°	13.5	0.68	11.7	1.44	8.7	0.74
	average	13.2	0.82	***11.7***	1.28	***8.6***	0.62
FAIL STRAIN (%)	**0°**	2.71	0.298	2.17	0.165	1.29	0.075
	90°	2.73	0.300	2.29	0.131	1.30	0.073
	average	***2.72***	0.293	***2.23***	0.157	***1.29***	0.072

SHEAR PROPERTIES

	TEMPERATURE (°C)	**-40**	**sd**	**25**	**sd**	**120**	**Sd**
STRENGTH (MPa)	**0°**	188	16.5	154	12.3	78.4	8.85
	90°	190	13.1	152	8.93	77.6	7.71
	average	***189***	14.6	***153***	10.5	***78.0***	8.13
MODULUS (GPa)	**0°**	5.04	0.37	4.96	0.86	3.44	0.42
	90°	5.52	1.05	4.53	0.35	3.19	0.36

Characteristic Differences in Tensile Behavior
Glass vs Carbon Reinforced Composites





Materials Group

- Material Characterization
- New Test Methods
- Data Base Generation
- Specifications
- Durability Prediction
- Data Acquisition System

Raising the Bar

Joining Group

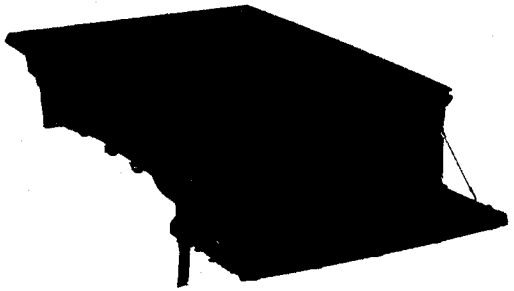
- Adhesive Screening & Selection
- Process Selection
- Design of Joints
- Joint Modeling
- NDT
- QC

New Technology

Focal Project Team

- Performance Specification
- Design and Analysis
- Design Verification
- Durability Testing
- Cost Modeling

Focal Project 2



Challenging the Limits

Processing Group

- Preform Developments
- Foam Core Improvements
- Tooling Concepts/Builds
- Molding Developments
- Flow Modeling

Supporting Technology

Government Projects

- ORNL Durability
- Adhesives Projects
- NCC Press Support
- INEEL Modeling

tjd fp2 interaction.ppt

UNDERGRADUATE EDUCATION IN COMPOSITE MATERIALS

James M. Whitney

Department of Civil and Environmental Engineering
and Engineering Mechanics
University of Dayton
300 College Park
Dayton, Ohio 45469-0243

Telephone: 937-229-3847
e-mail James.Whitney@notes.udayton.edu

James M. Whitney

UNDERGRADUATE EDUCATION IN COMPOSITE MATERIALS

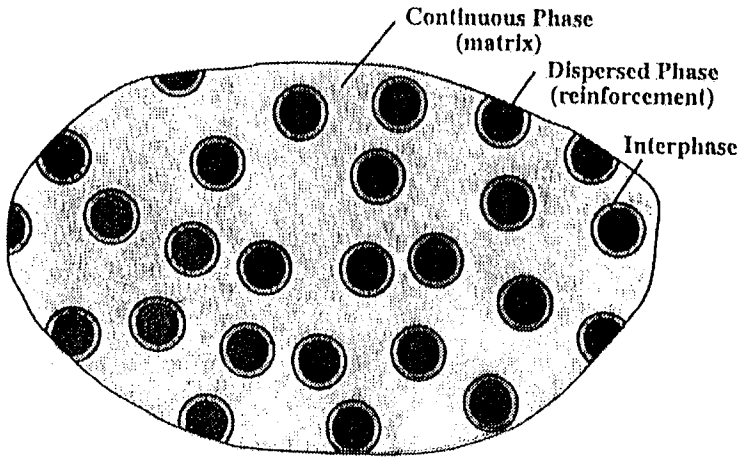
James M. Whitney
Torley Chair For Composite Materials Engineering

Dept. of Civil & Environmental Engineering and Engineering Mechanics

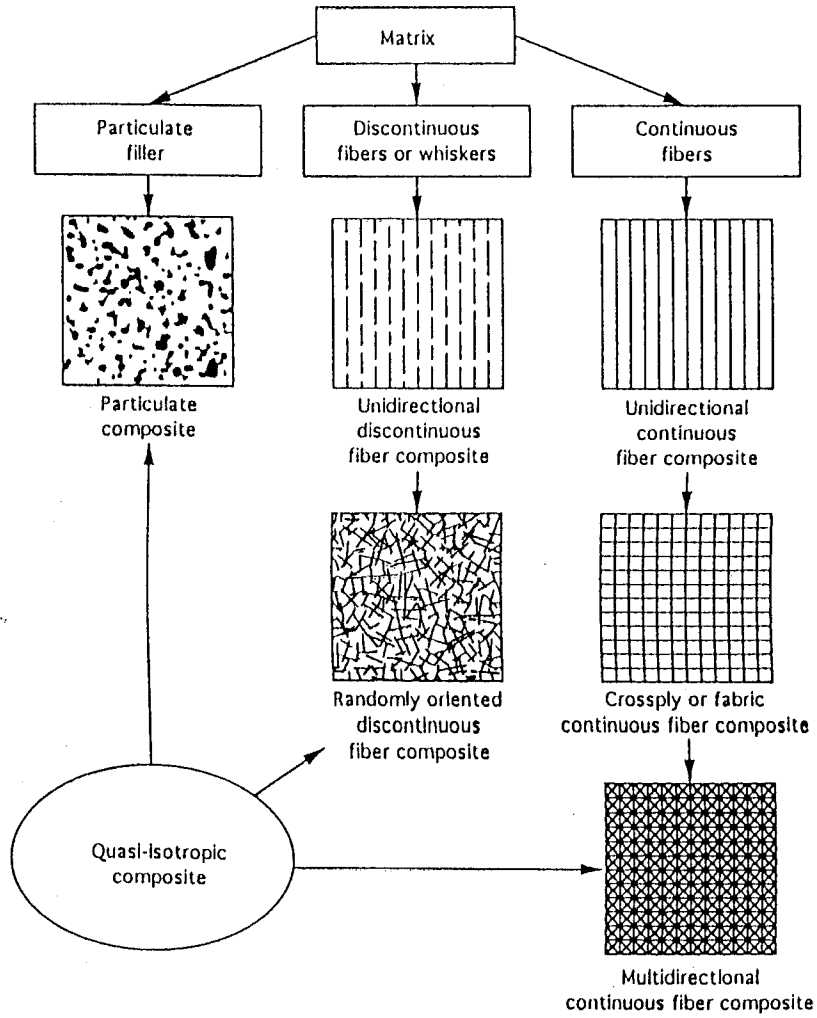
University of Dayton
Dayton, Ohio

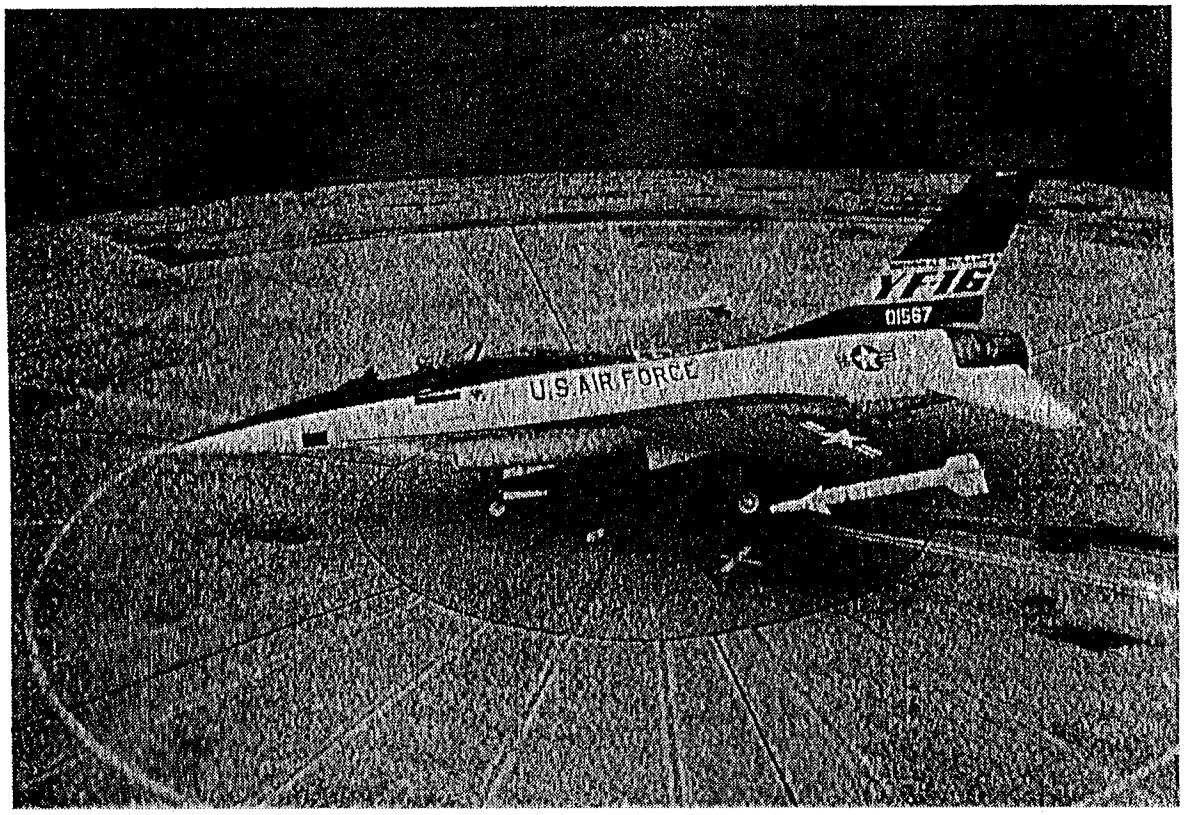
DEFINITION OF A COMPOSITE MATERIAL

- Material with two or more distinctive phases at the macroscopic scale
- Stiffer and stronger phase called reinforcement which is either continuous or discontinuous
- Weaker phase called matrix or binder
- Sometimes an additional phase called an interphase exists between the reinforcement and the matrix

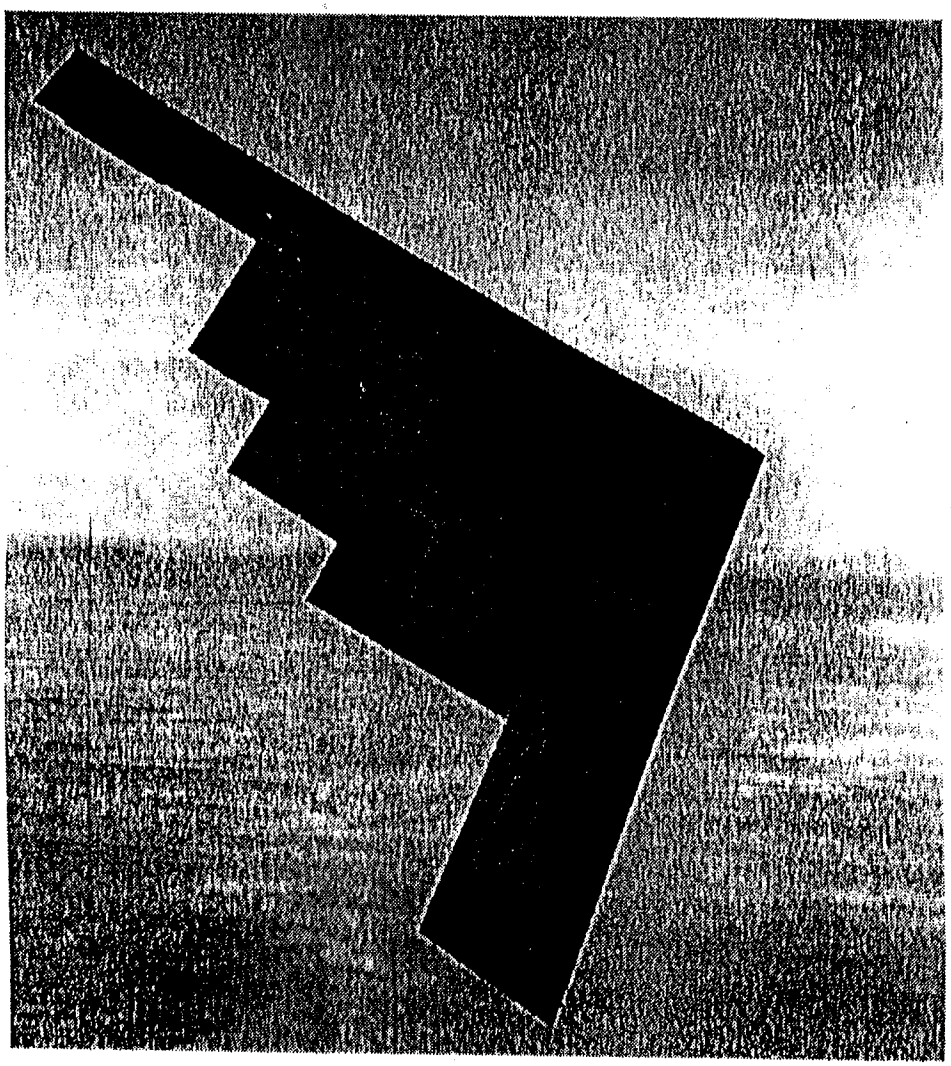


CLASSIFICATION OF COMPOSITE SYSTEMS



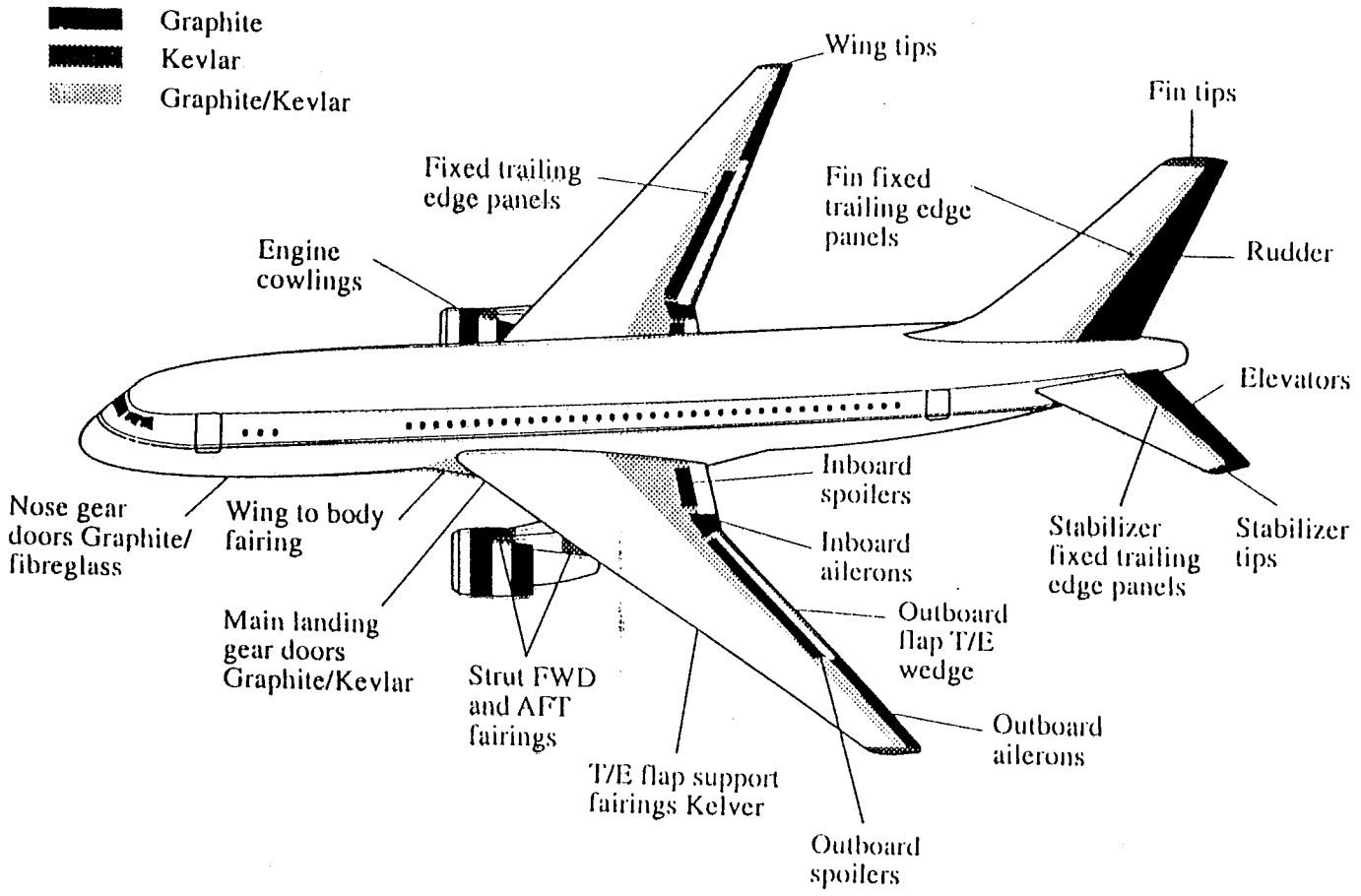


General Dynamics YF-16 with graphite/epoxy horizontal and vertical stabilizer



B-2 STEALTH BOMBER

COMPOSITE APPLICATIONS ON THE BOEING 767



DESIGN DIFFICULTIES DUE TO LACK OF TRAINING:

- Composite materials offer a unique opportunity to design a material to perform a desired function.

- This opportunity is not being fully explored because of a lack of innovative design. Most design engineers have grown-up with metals technology ("aluminum syndrome"), i.e. they feel more comfortable if the material looks like a metal.

- Composite materials are often used only as a substitute for a metal part, which does not allow the unique properties of a composite to be fully exploited.

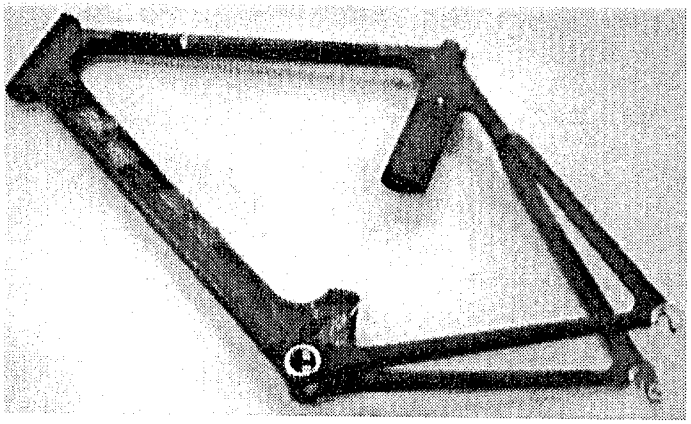
- If one were to approach the design process with the concept of using composite materials, the part or structure could look quite different. Classic example is the X-29 forward swept wing aircraft built by Grumman.

MOST COMPOSITE MATERIAL COURSES TAUGHT AT GRADUATE LEVEL

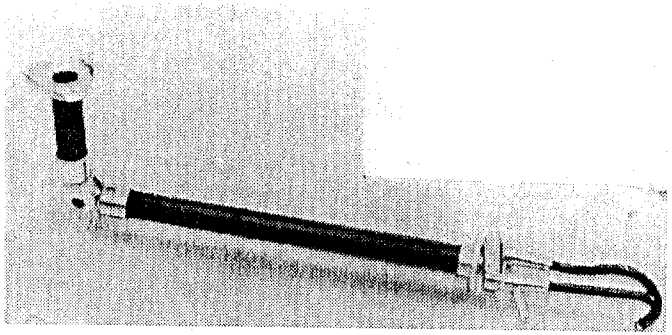
Early Centers Established

University of Delaware Center for Composite Materials

Composites Center at Virginia Tech

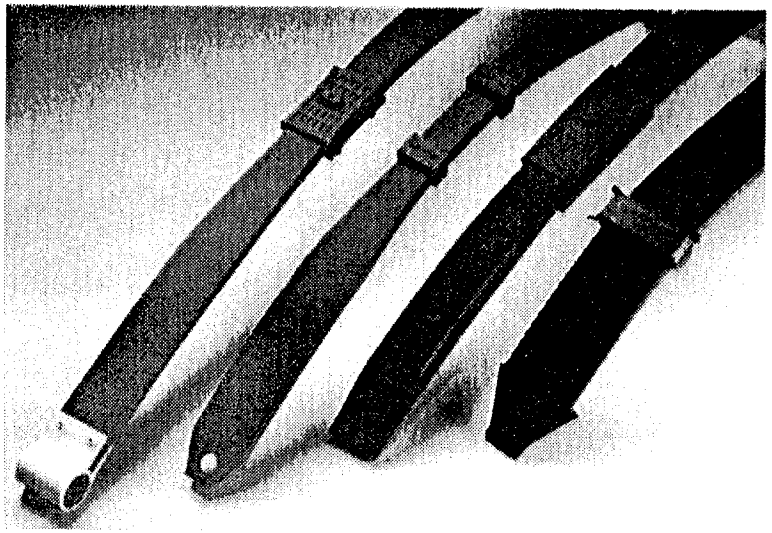


CARBON/EPOXY BICYCLE FRAME
WEIGHING 3 LBS



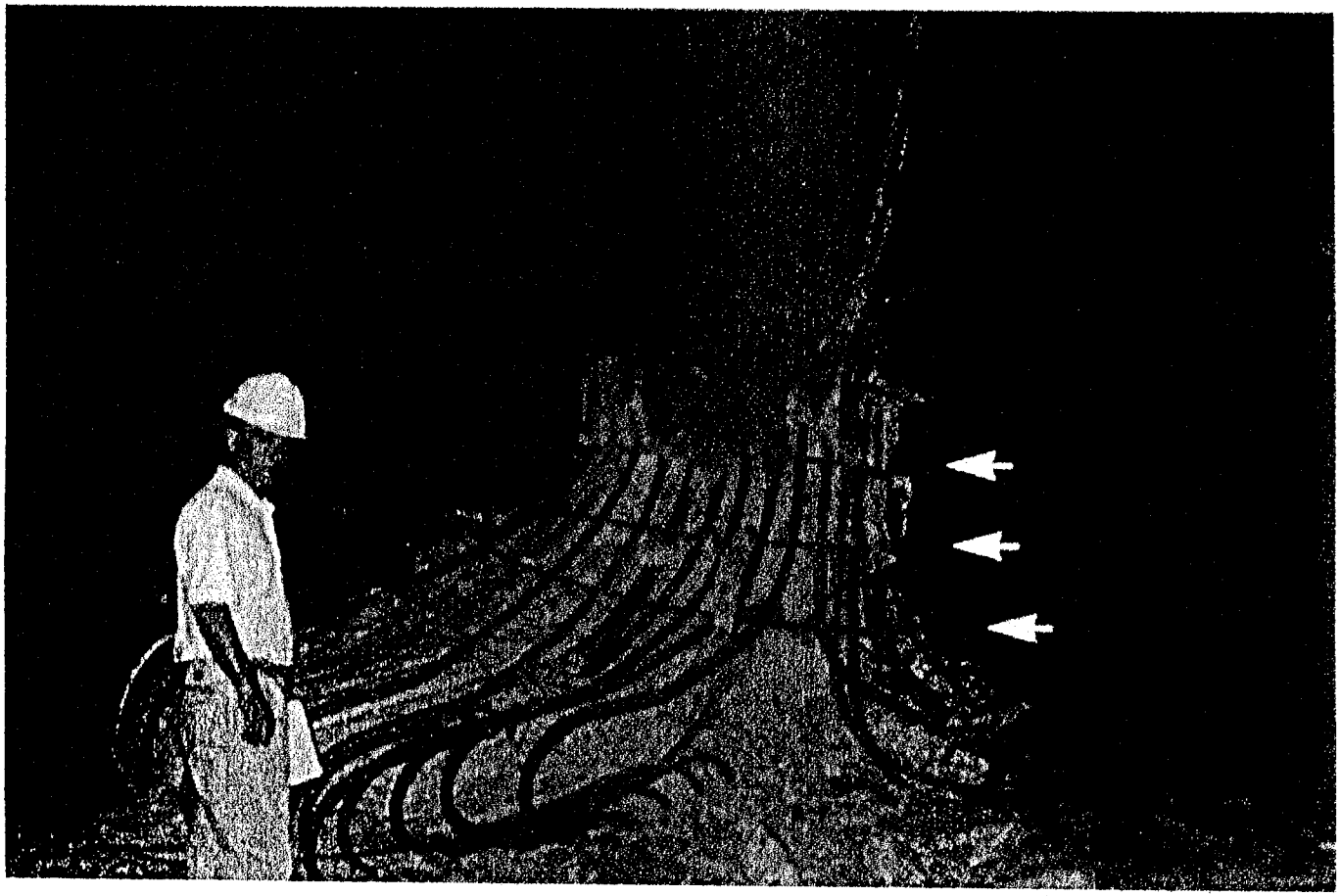
ARTIFICIAL LIMB WITH
CARBON/EPOXY COMPONENTS

DRIVE SHAFT – FORD VAN



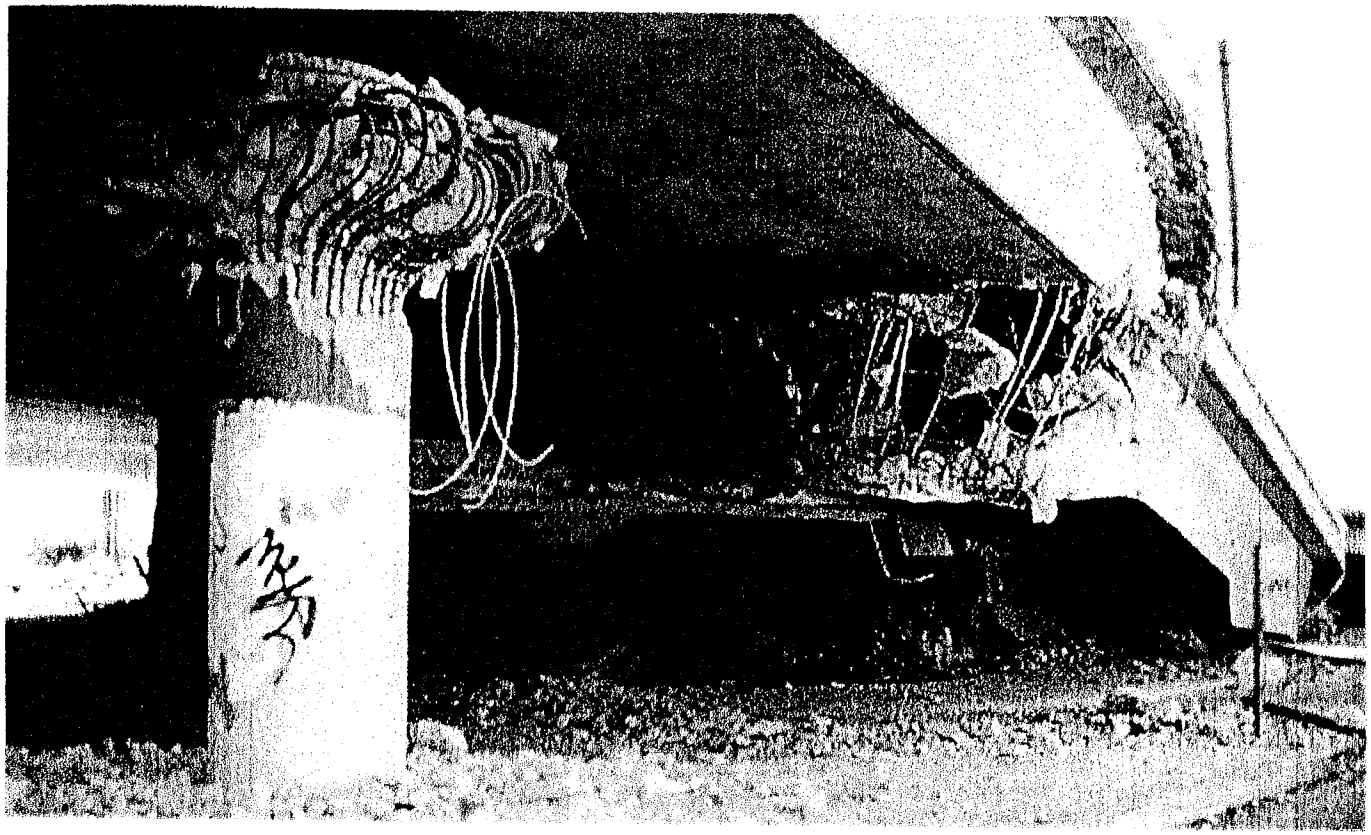
CORVETTE LEAF SPRINGS

The Problem - Insufficient Horizontal Reinforcement



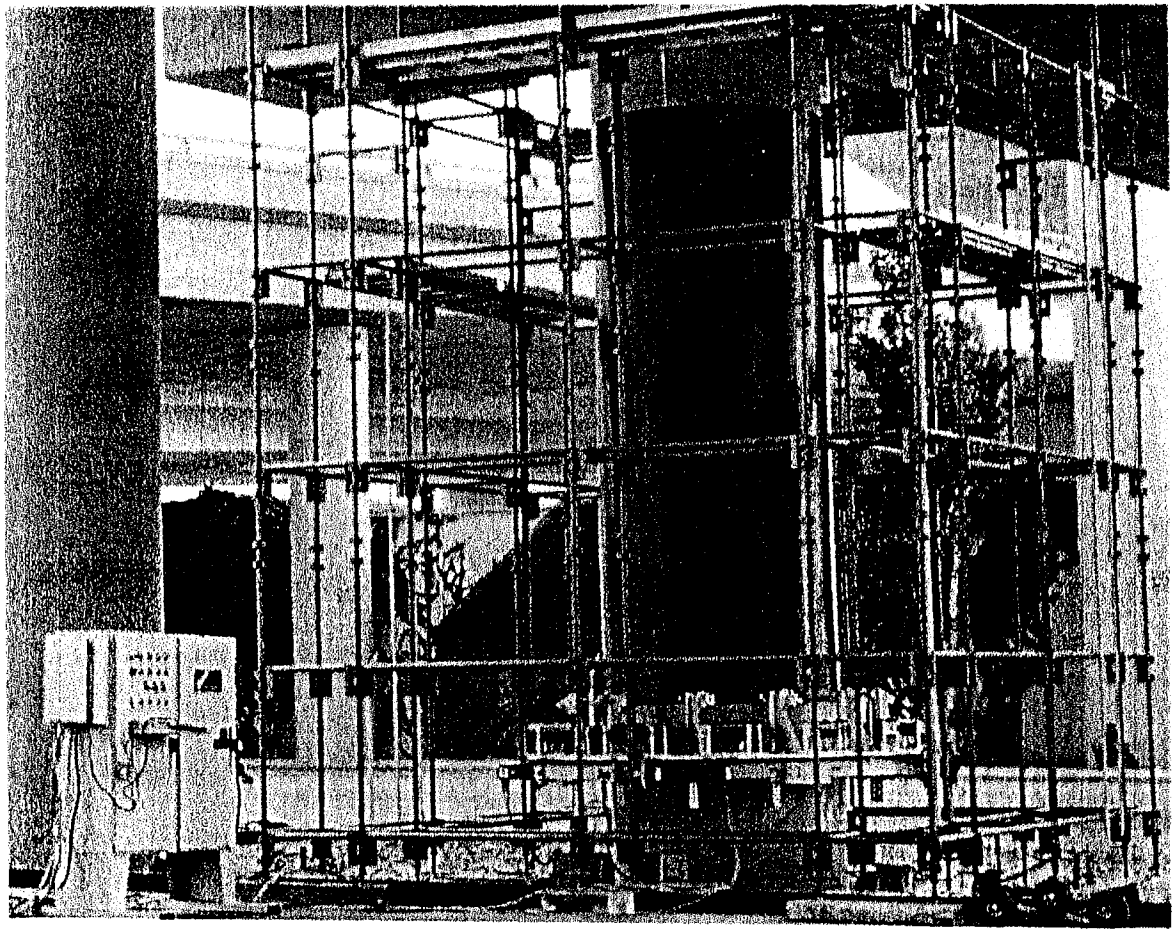
Northridge, California Earthquake, 1994

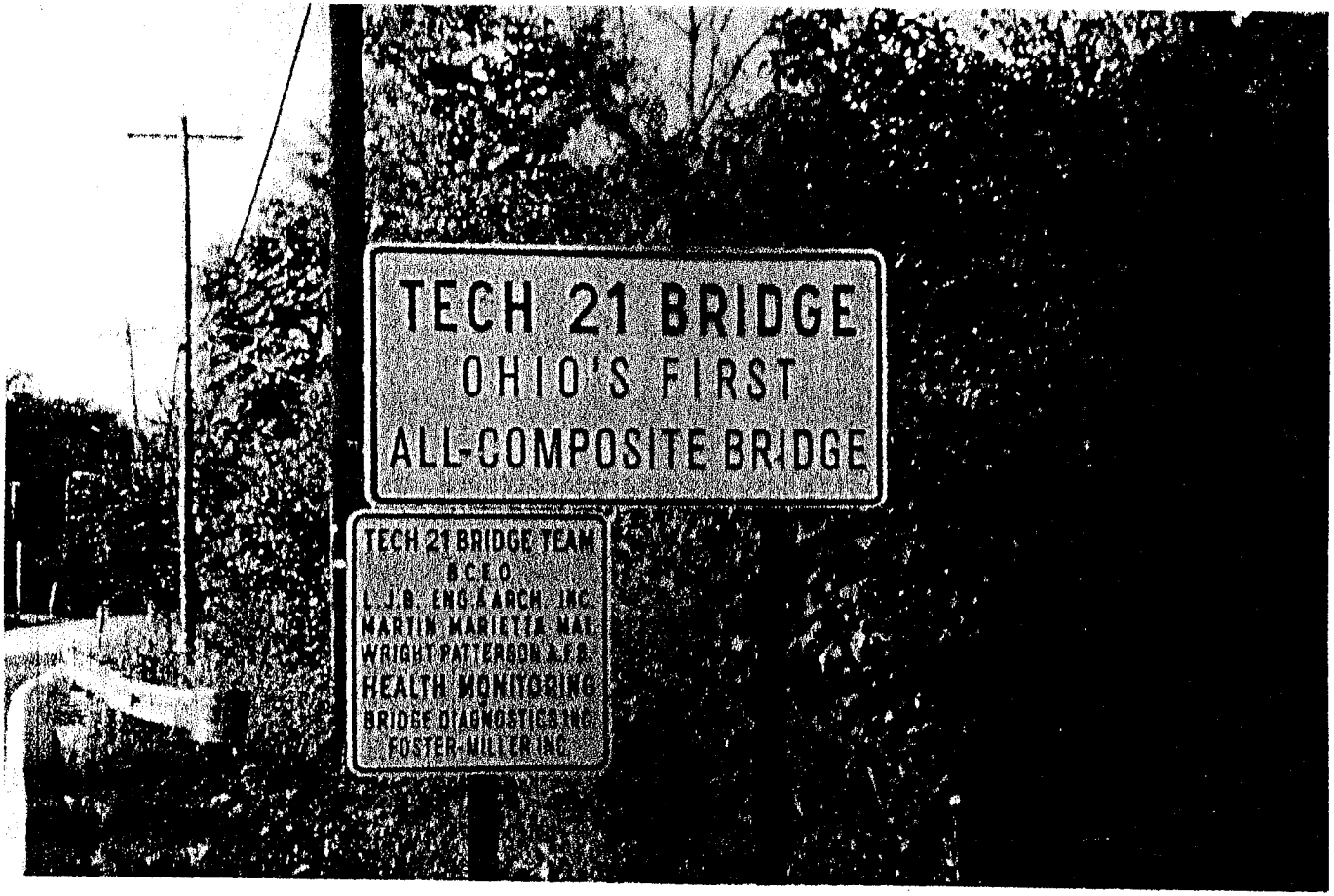
Consequence - Freeway Collapse



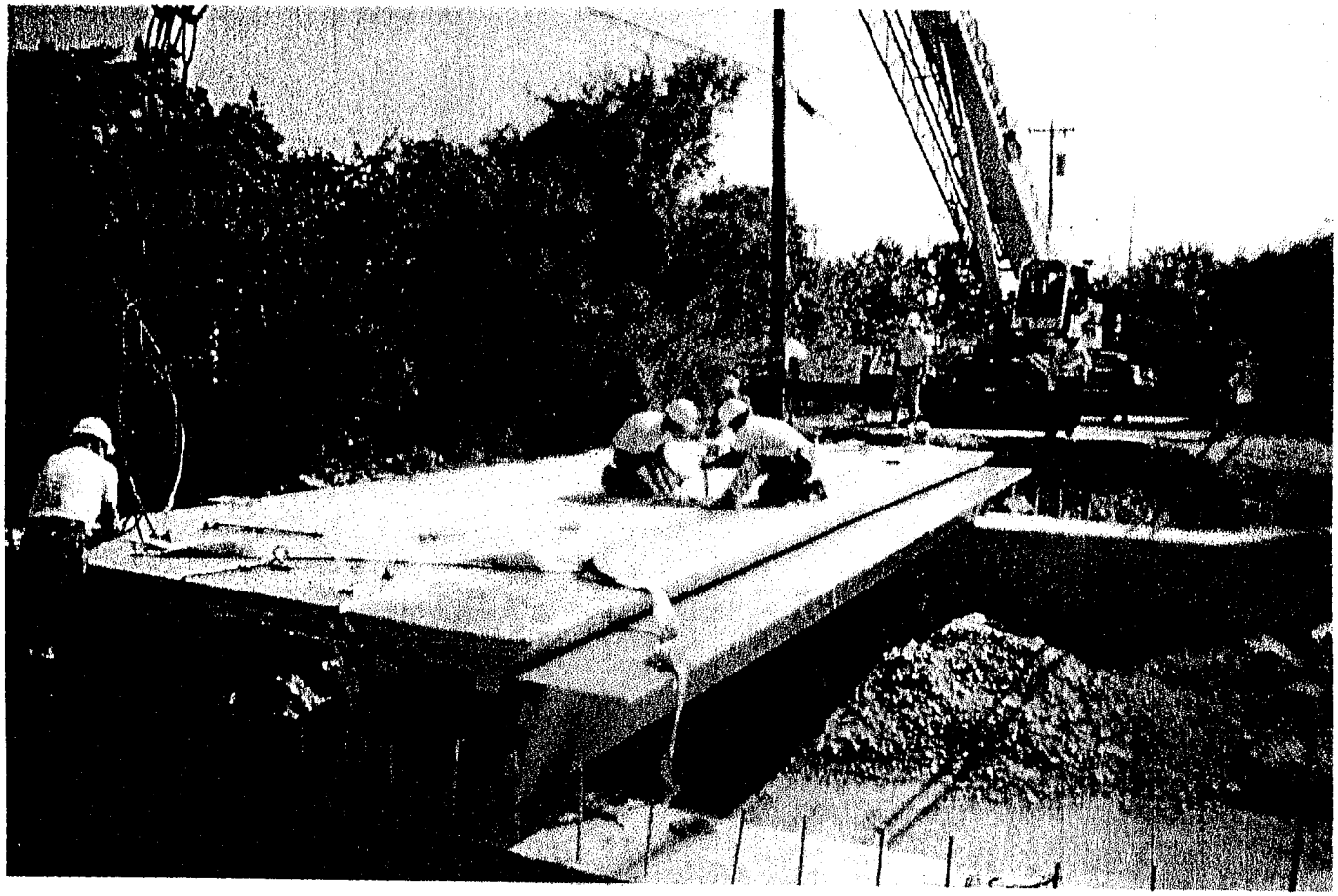
I-10 Freeway, Los Angeles, Northridge Earthquake, 1994

The High-Tech Solution - Carbon Composites
- 5 to 10 times faster - Cost Effective - No Corroison




TECH 21 BRIDGE
OHIO'S FIRST
ALL-COMPOSITE BRIDGE
TECH 21 BRIDGE TEAM
S.C.E.O.
L.J.B. ENG.&ARCH. INC.
MARTIN MARIETTA MAT.
WRIGHT PATTERSON A.F.B.
HEALTH MONITORING
BRIDGE DIAGNOSTICS INC.
FOSTER-MILLER INC.

Tech 21 Bridge Deck Installation



Tech 21 Bridge Completed

UNDERGRADUATE ACTIVITY

MIT - Aerospace Engineering

Winona State University - Degree in Composite Materials Engineering (Started 1990 - ABET Accredited 1995)

SAMPE - Bridge Competition

CHALLENGE TO UNDERGRADUATE EDUCATION:

- Most undergraduate Engineers leave the university with the notion that the world is made of homogeneous metals.

- Few students attend graduate school.

- Civil engineers are an exception to this as they deal with reinforced concrete. However, they are not well grounded in fundamentals relative to contemporary composites such as graphite fiber reinforced materials.

- Crowded undergraduate curriculums leave little room to add additional courses.

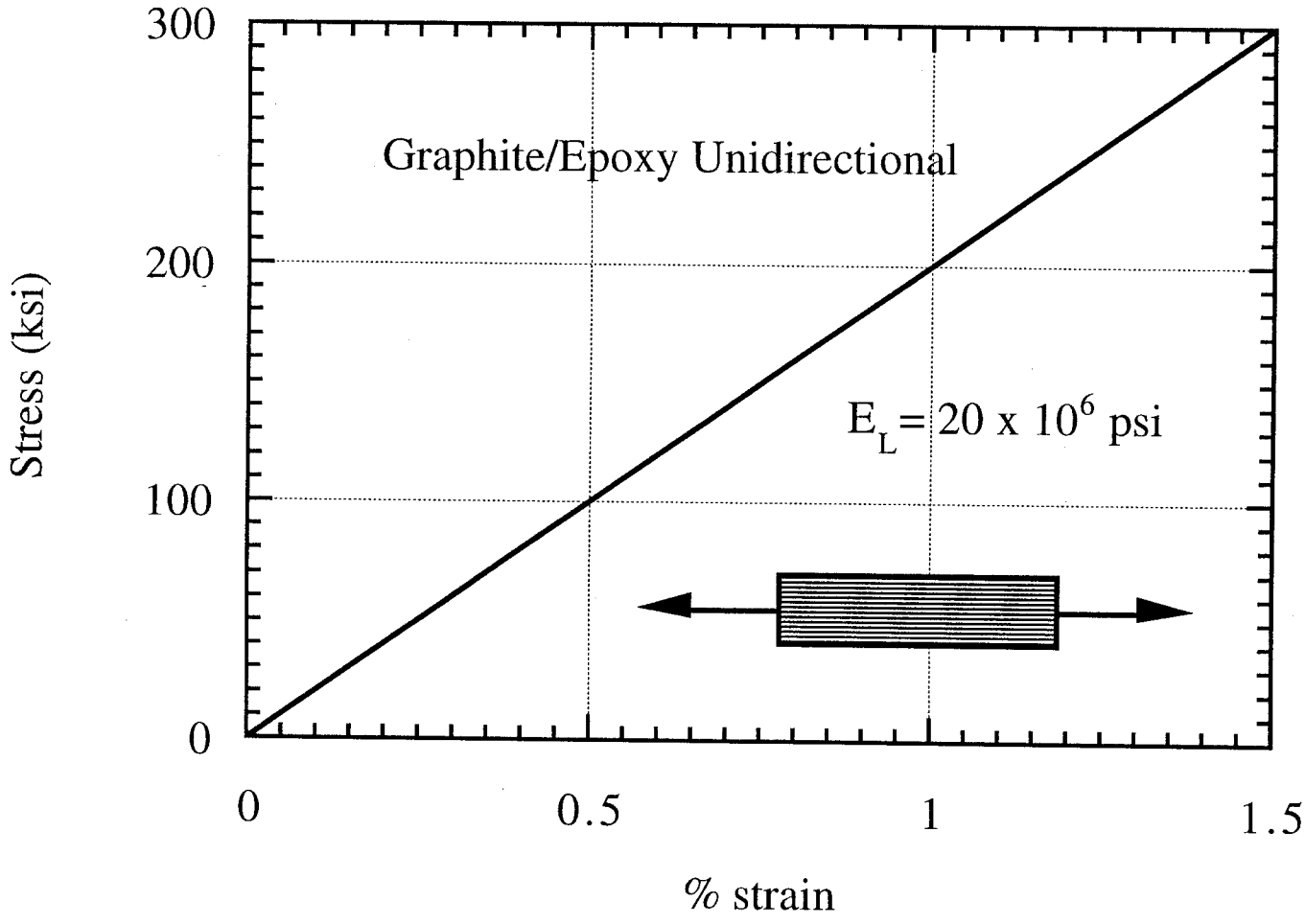
- Emphasis needs to be on restructuring some of the traditional courses to include information relative to composite matrials technology.

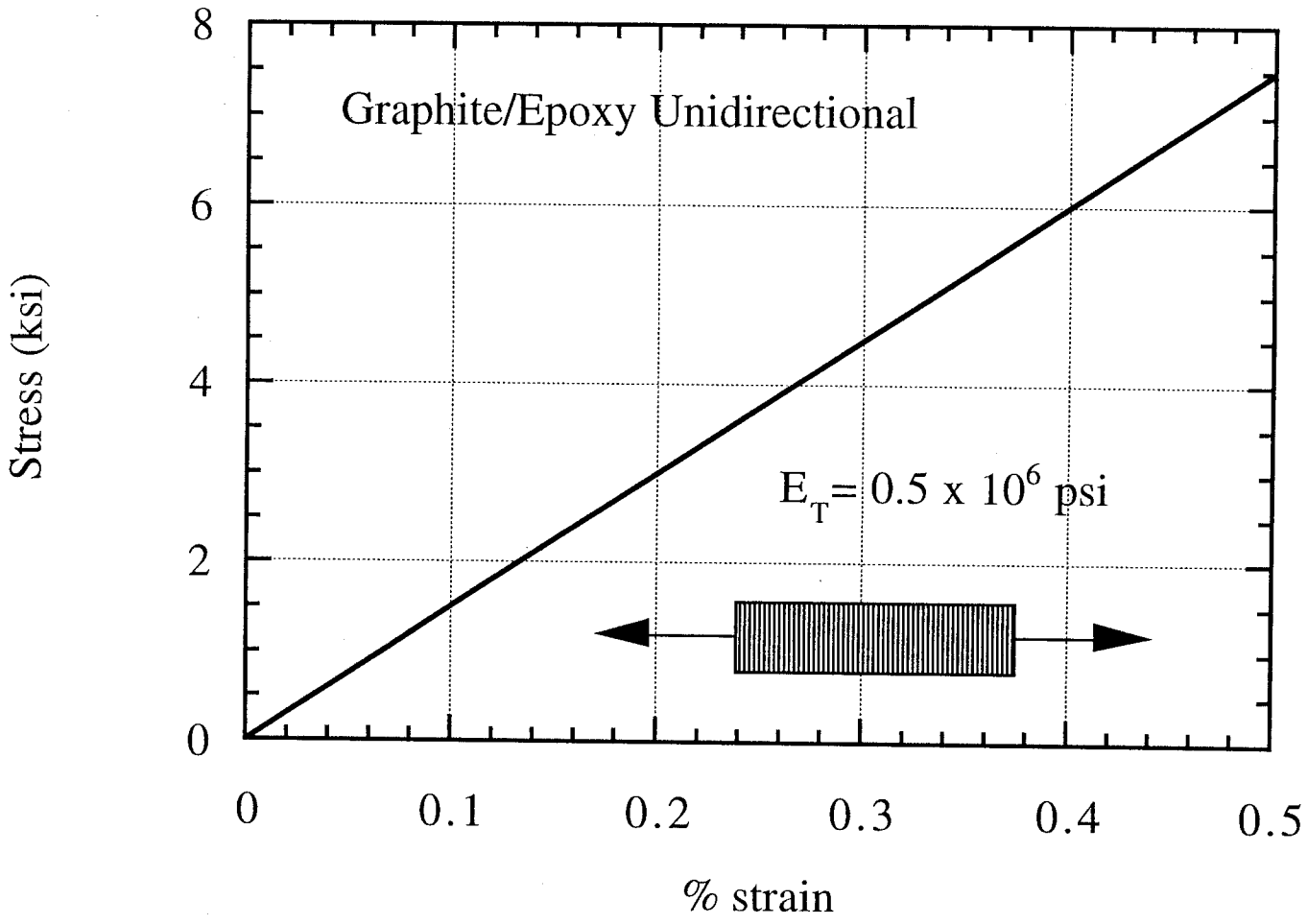
ENGINEERING MATERIALS

- Introduction to composite materials which would include definition, classes of composites, industrial applications, why composites, specific properties, and brief history.
- Discussion of constituent materials: fibers/reinforcements and matrix materials.
- Manufacturing processes.

OTHER COURSES

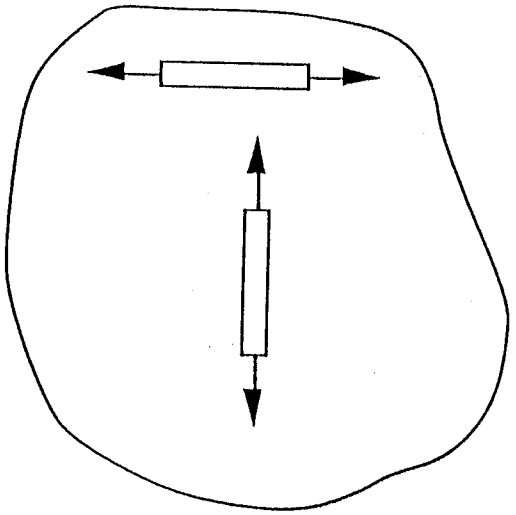
- Heat transfer: directional dependence of thermal conductivity and diffusivity
- Strength-of-materials
- Aerospace structures
- Civil engineering structures
- Experimental stress analysis: tension test on composite in different direction


300
200
100
0
Stress (ksi)
Graphite/Epoxy Unidirectional
$E_L = 20 \times 10^6$ psi
0
0.5
1
1.5
% strain


Graphite/Epoxy Unidirectional
$E_T = 0.5 \times 10^6$ psi
Stress (ksi)
% strain
0
2
4
6
8
0
0.1
0.2
0.3
0.4
0.5

ISOTROPIC MATERIAL

PROPERTIES INDEPENDENT OF DIRECTION



$$\varepsilon_x = \frac{1}{E}[\sigma_x - \nu(\sigma_y + \sigma_z)]$$

$$\varepsilon_x = \frac{1}{E}[\sigma_y - \nu(\sigma_x + \sigma_z)]$$

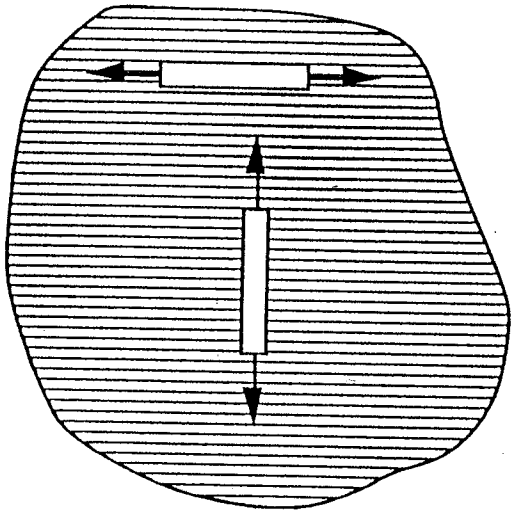
$$\varepsilon_x = \frac{1}{E}[\sigma_z - \nu(\sigma_x + \sigma_y)]$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G}, \quad \gamma_{xz} = \frac{\tau_{xz}}{G}, \quad \gamma_{yz} = \frac{\tau_{yz}}{G}$$

$$G = \frac{E}{2(1+\nu)}$$

ORTHOTROPIC MATERIAL

PROPERTIES DEPEND ON DIRECTION



$$\varepsilon_x = \frac{1}{E_x}\left[\sigma_x - \left(\nu_{xy}\sigma_y + \nu_{xz}\sigma_z\right)\right]$$

$$\varepsilon_y = -\frac{\nu_{xy}}{E_x}\sigma_x + \frac{1}{E_y}\left(\sigma_y - \nu_{yz}\sigma_z\right)$$

$$\varepsilon_z = -\frac{\nu_{xz}}{E_x}\sigma_x - \frac{\nu_{yz}}{E_y}\sigma_y + \frac{\sigma_z}{E_z}$$

$$\gamma_{xy} = \frac{\tau_{xy}}{G_{xy}}, \quad \gamma_{xz} = \frac{\tau_{xz}}{G_{xz}}, \quad \gamma_{yz} = \frac{\tau_{yz}}{G_{yz}}$$

	σ_x	σ_y	σ_z	ΔT
ε_x	$\frac{1}{E_x}$	$-\frac{\nu_{yx}}{E_y}$	$-\frac{\nu_{zx}}{E_z}$	α_x
ε_y	$-\frac{\nu_{xy}}{E_x}$	$\frac{1}{E_y}$	$-\frac{\nu_{zy}}{E_z}$	α_y
ε_z	$-\frac{\nu_{xz}}{E_x}$	$-\frac{\nu_{yz}}{E_y}$	$\frac{1}{E_z}$	α_z

Maxwell Reciprocity Relations

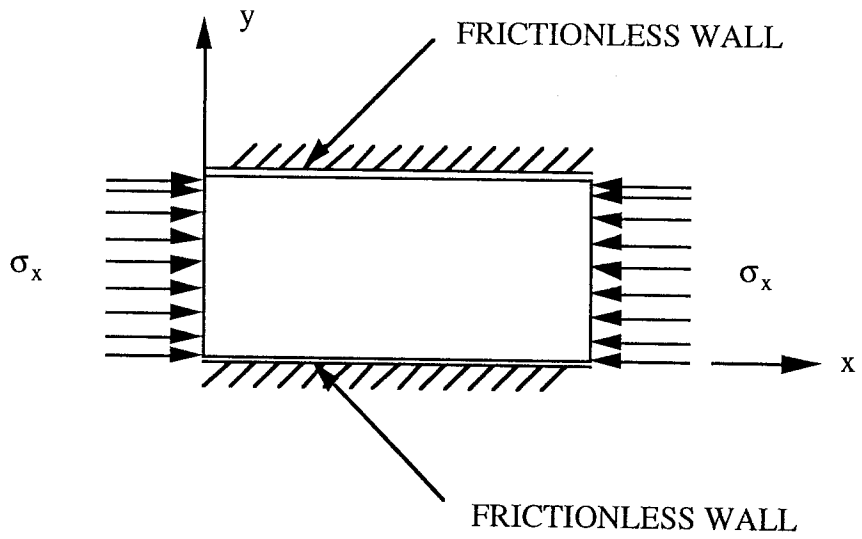
$$\frac{\nu_{yx}}{E_y} = \frac{\nu_{xy}}{E_x}, \quad \frac{\nu_{zx}}{E_z} = \frac{\nu_{xz}}{E_x}, \quad \frac{\nu_{zy}}{E_z} = \frac{\nu_{yz}}{E_y}$$

SAMPLE PROBLEM

An orthotropic plate is subjected to a uniaxial compression load with the adjacent sides constrained as shown below. The plate is also subjected to a temperature change $\Delta T = 200°F$. The plate has the following properties

$$E_x = 20 \times 10^6 \text{ psi}, E_y = 1.5 \times 10^6 \text{ psi}, \nu_{xy} = 0.3,$$
$$\alpha_x = -0.5 \times 10^{-6}/^o F, \alpha_y = 15 \times 10^{-6}/^o F$$

If $\varepsilon_x = -1.5 \times 10^{-3}$ in/in, determine the normal stresses σ_x and σ_y. Assume the gap between the plate and the walls are zero (i.e. $\delta_{gap} = 0$).



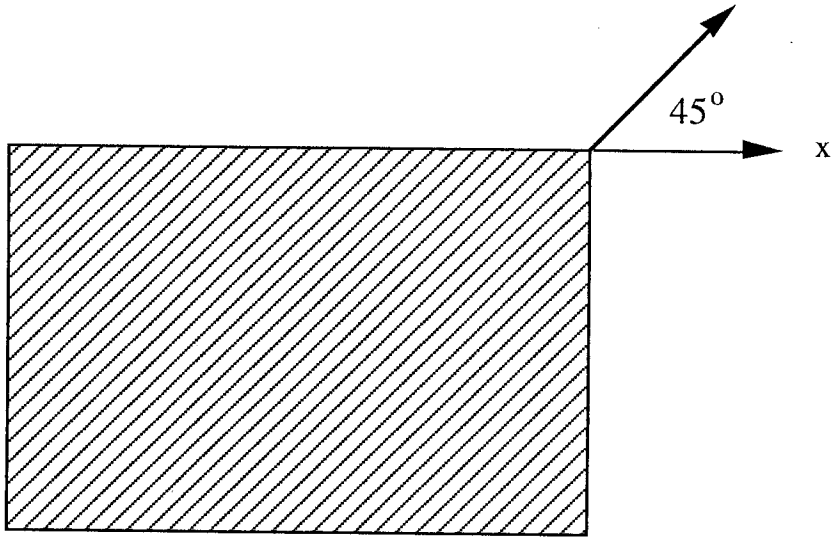
SOLUTION

$$\varepsilon_x = -\,0.0015 = \frac{(\sigma_x - \nu_{xy}\sigma_y)}{E_x} + \alpha_x \Delta T$$

$$\varepsilon_y = 0 = -\frac{\nu_{xy}}{E_x}\sigma_x + \frac{1}{E_y}\sigma_y + \alpha_y \Delta T$$

$$\sigma_x = -29.95 \text{ ksi}, \; \sigma_y = -5.174 \text{ ksi}$$

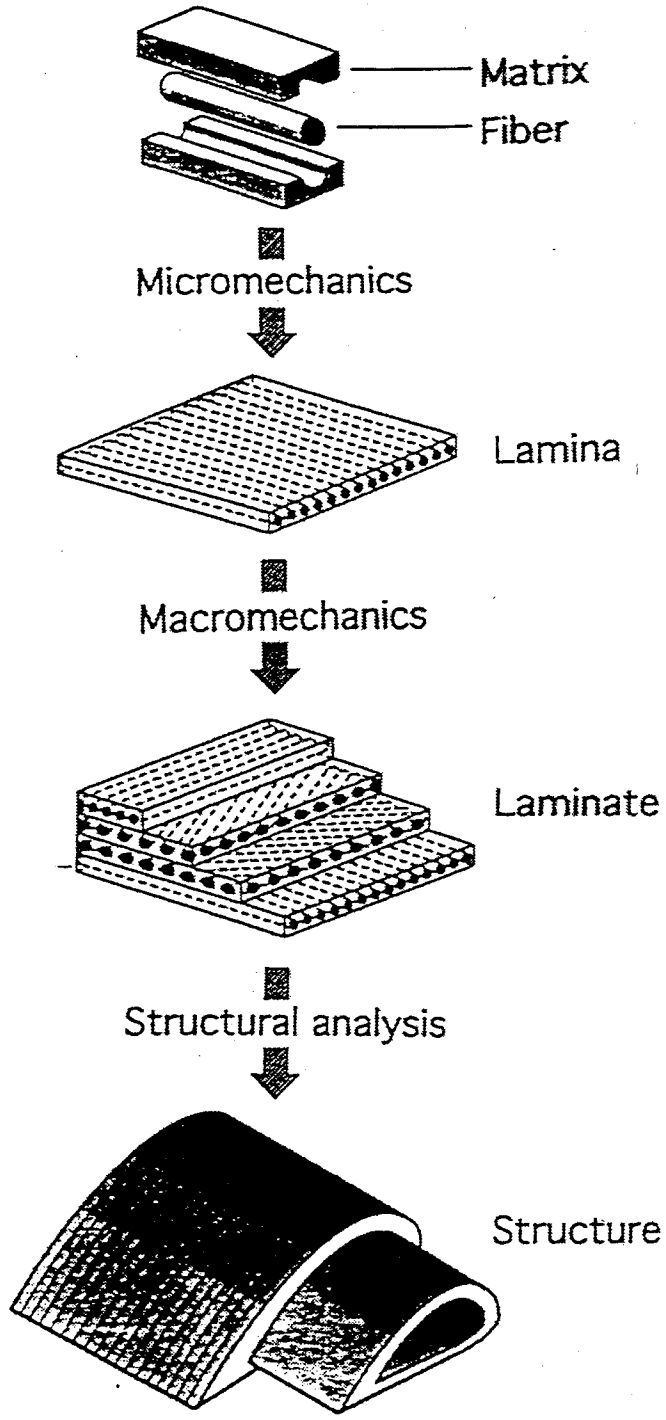
EXAMPLE PROBLEM



Fiber Reinforced Composite: $\sigma_x = -15$ ksi, $\sigma_y = 10$ ksi, $\tau_{xy} = 0$

Find: τ parallel to fibers, σ parallel and perpendicular to the fibers

Mechanics of Composite Materials



WORKSHOP PRESENTATIONS

Teaching With Simulation

The Sinclair Industrial Engineering Technology Department Welcomes National Educators' Workshop Attendees

Tom Carlisle

Teaching With Simulation

The Sinclair
Industrial Engineering Technology
Department
Welcomes
National Educators' Workshop
Attendees

Teaching With Simulation

Teaching With Simulation

Agenda

- Introduction
- Defined Our Instructional Methods
- Curriculum Development Methods
- Use Of Power Point
- Established Standard Products
- Equipment & Lab Development
- Use Of Virtual Simulation
- Results To Date
- The Future

Introduction

- Reasons For Using Simulation
  - Desire to change to Activity Based Teaching
  - Simulation is a more effective way for faculty to teach and for students to learn
  - Increased student interest and participation
  - Improved correlation between curriculum and the "Real World"

Defined Our Instructional Methods

- Activity Based Instruction
  - Some lecture with increased structured experiences, via simulation, in the classroom and lab
- Use of Power Point
  - Includes use of photographs, sound, graphs, charts, illustrations, clip art and animation
  - This became the department standard

Defined Our Instructional Methods

- Lab Flexibility
  - Almost all the equipment in the IET lab can be easily moved
  - The lab equipment can be quickly rearranged to set up almost any type of production system or situation
  - Several different types of equipment are available
  - Use of Creform building materials provides ability to quickly and cheaply design and build new equipment and work places

Defined Our Instructional Methods

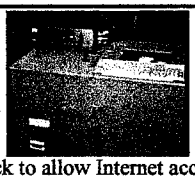
- MS Office installed on all full time faculty computers
- Part time faculty using Power Point files or developing Power Point courses also have Power Point installed on their home computers
- ZIP drives also installed on all full time faculty computers and loaned to part time faculty
- Training provided

Defined Our Instructional Methods

- Computer Carts designed and built for classroom and lab use
- Computer Cart Specifics
  - Contained in a cabinet built with plywood and Creform
  - Computer with the normal floppy, CD-ROM & hard drives
  - Monitor
  - Video projector

Defined Our Instructional Methods

- ZIP drive
- VCR
- Sound system
- Printer



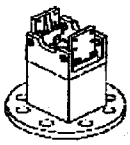
- Telephone jack to allow Internet access
- Extension cord with a take-up reel
- On a heavy duty frame with casters
- Sized to fit through the standard sized classroom door

Defined Our Instructional Methods

- All locks opened by one key
- Master power switch
- Slots in the cabinet allow access to the drives without opening the doors

Established Standard Products

- Often students have trouble relating what they learned in one class to what they are learning in their current courses and products are needed to support simulation
- Two products are used to address these problems
  - "Wagons-R-Us"
  - Robotic Gripper



Established Standard Products

"Wagons -R- Us"

- A product line of six small simple, scale wagons and one tractor has been designed
- Made from KNE'X

- Used to teach initial manufacturing and IET principles
- Used in several courses to provide related activities and tie the courses together

Established Standard Products

- A complete set of manufacturing documentation is available as an aid to developing simulations
  - Part numbering, sub-assembly and product identification system
  - Processing plans and routings
  - Sequence diagrams
  - Sales and shop order forms
  - Bills of Material

Established Standard Products

- Short company history
- Tooling, material handling equipment and CNC machining fixtures and CNC programs
- Simulated shop floor layout and warehouse
- Wagons -R- Us is used in the lower level courses to introduce manufacturing and Industrial Engineering concepts
- Used for providing related simulation experiences

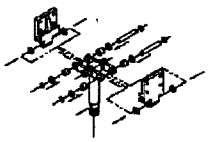
Established Standard Products

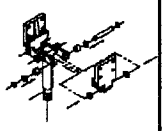
- Students take simulations and projects completed in one course and expand upon them in the next
- Wagons -R- Us data used in course development as a means to provide consistent instruction and course examples
- W -R- U is built into the Power Point notes

Established Standard Products

Robotic Gripper

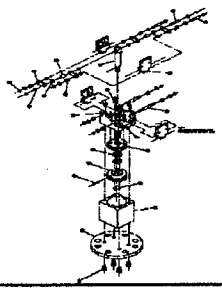
- Developed as part of an NSF grant peoject
- Replaces W-R-U in higher level courses
- Provides a more complex and realistic product to teach with





Established Standard Products

- Manufacturing and product data is available
  - Part numbers
  - AutoCad drawings
  - Process plans and routings
  - Bill of Material
  - Material specifications



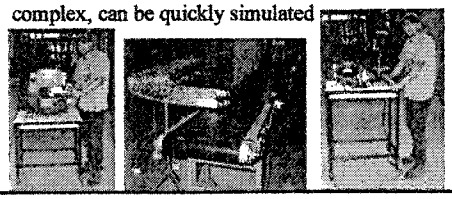
Equipment & Lab Development

- Extensive planning and development has gone into the IET Lab
- Bob Hazel is the ***KEY*** to our lab development

Tom Carlisle 20

Equipment & Lab Development

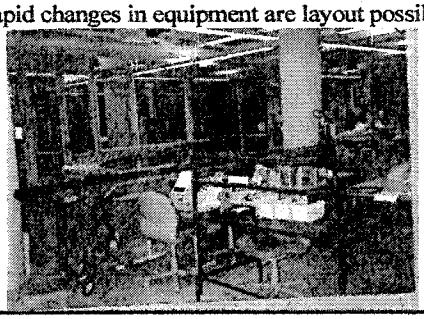
- Almost everything in the lab can be easily repositioned
  - Rapid changes in equipment layout possible
  - Almost any manufacturing operation, from simple to complex, can be quickly simulated



Tom Carlisle 21

Equipment & Lab Development

- Rapid changes in equipment are layout possible



Tom Carlisle 22

Equipment & Lab Development

- Almost any manufacturing operation, from simple to complex, can be quickly simulated

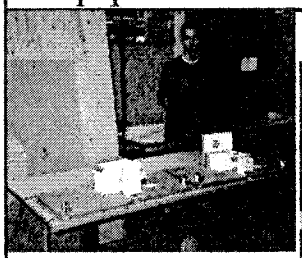
Tom Carlisle 23

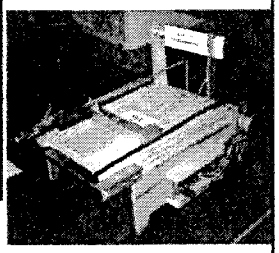
Equipment & Lab Development

- Special equipment has been designed and built to simulate more complex and expensive production machinery
  - Automated machinery processes
  - Manual machinery processes
  - These cost a small fraction of the cost of full size equipment
  - Sized to support both KNE'X and the gripper
  - Very flexible to use

Tom Carlisle 10/22/2000 24

Equipment & Lab Development

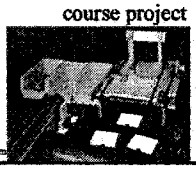


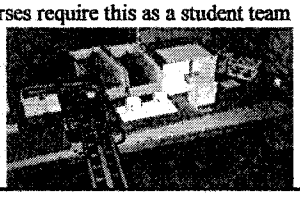


Tom Carlisle 10/22/2000 25

Equipment & Lab Development

- Use of KNE'X, the Gripper and Creform allow students to design, test, evaluate and demonstrate their own workplaces, tooling and manufacturing plans
  - Many IET courses require this as a student team course project





Equipment & Lab Development

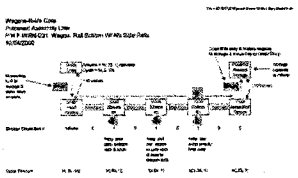
- Other equipment provided
  - Belt and skate wheel conveyors
  - Band saw
  - Drill press
  - Grinder
  - Hand tools
  - Tool hangers
  - Tooling, fixtures and packaging

Equipment & Lab Development

- A screen and white board is provided
- Small CNC machines allow us to tie machine tools into student designed processes
- In the IET lab students can be provided with simulated but realistic problems and assignments

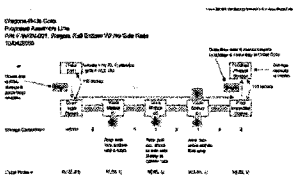
Use Of Virtual Simulation

- Using ProModel simulation software we also combine physical and computer simulation



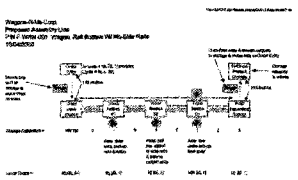
Use Of Virtual Simulation

- Using the products, materials and equipment described a manufacturing system can be set up



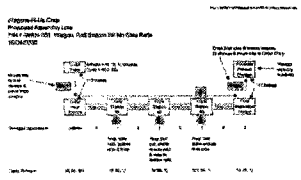
Use Of Virtual Simulation

- The students collect information about it and program and run a computer simulation



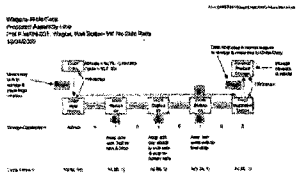
Use Of Virtual Simulation

➔Then we run the physical simulation and compare it to the computer run results



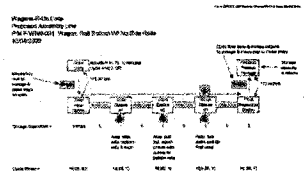
Use Of Virtual Simulation

➔Or, we can go in the opposite direction and design a process, simulate an then build it



Use Of Virtual Simulation

➔An example of this will be shown after this presentation



Results To Date

➔To date almost all IET courses have been impacted by the simulation methods presented

➔Curriculum improvement is an ongoing activity

➔Use of W-R-U and the Robotic Gripper has increased student ability to see the integrated nature of their knowledge

Results To Date

➔Use of ProModel and the products, materials and equipment described enable us to use simulation in many effective ways in many courses

➔Use of Power Point has improved class quality and consistency

➔Student interest and participation has improved

➔This is just a ***FUN*** way to teach and learn

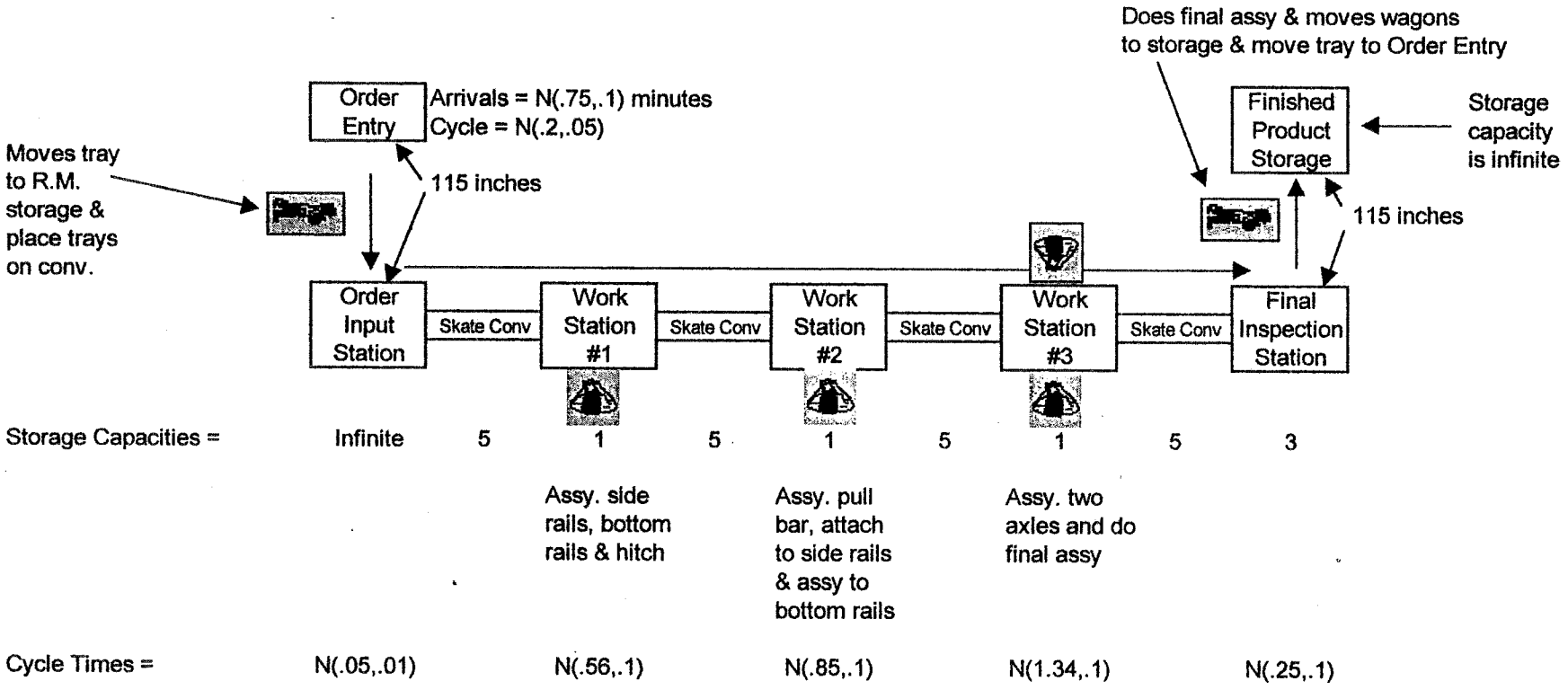
The Future

➔Efforts will continue

- ➔All courses will be continuously improved
- ➔Additional simulations will, where appropriate, be included

File = ZIP/IET-207/Spread Sheets/W-R-U Assy Model 2.xls

Wagons-R-Us Corp.
Proposed Assembly Line
P/N F-WRN-001, Wagon, Rail Bottom W/ No Side Rails
10/04/2000



Programmable Powder Preform Process (P4) Workshop

Developing Low Cost Composites

Mike Melton, Scott Reeve, Correen Schneider
National Composites Center

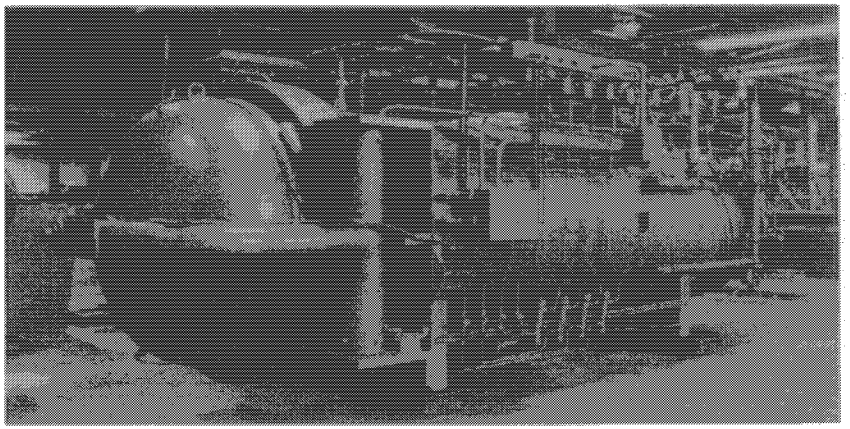
Workshop Agenda

- Review of current industry processes
- Overview of new, low cost P4 process
- Hands-on part fabrication using current industry processes
- Demonstration of part fabrication using P4

Existing Process - Prepreg

- High Quality, High Performance, High Cost

- Hand lay-up of prepreg
- Cure in Autoclave
- Aircraft and recreational products
- Labor Intensive
- Size Limitations



Existing Process – Spray Up

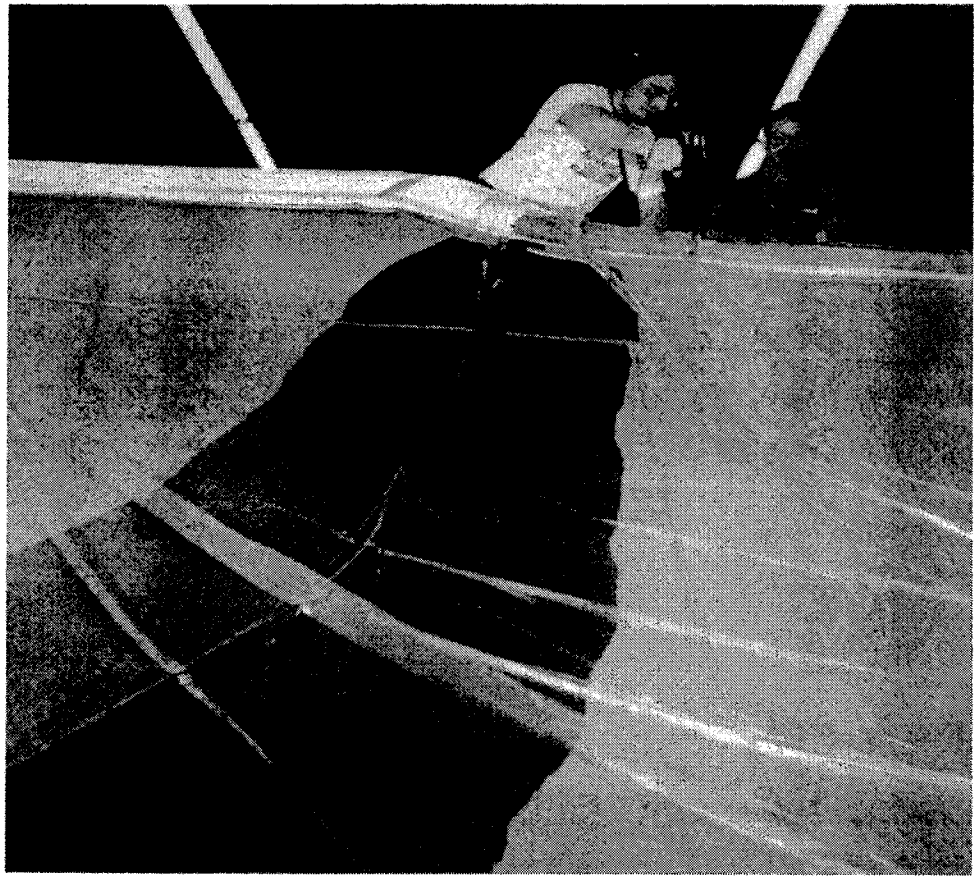
- Low Cost, Low Quality, Low Performance

- Spray up of chopped fibers & resin
- Mixture is sprayed into an open mold - emissions are an issue
- Dimensional control of mold side only
- Poor control of dimensions and fiber /resin content
- Boats, shower/tub, seats

Existing Process – Infusion of Fabric Preforms

- High Performance, Good Quality, Medium Cost,

- Hand lay-up of dry fabrics
- Infused with resin
  - –Resin Transfer Molding (RTM)
  - –Vacuum Assisted RTM (VARTM)
- Low pressure – lower tooling costs



Programmable Powdered Preform Process (P4)

- Low Cost, High Quality, Medium Performance

- Fully automated process for chopping and spraying fiber
- Rapid fabrication of fiber preforms
- Reduced assembly
- Potential net shape preforms
- Low material waste

Hands-On Fabrication using Existing Processes

- Compound curvature part
- Hand layup of prepreg
  - Demonstration
  - Hands-on fabrication by participants
- Layup of dry fiber fabric
  - Demonstration
  - Hands-on fabrication by participants

P4 Demonstration

- Demonstration of part fabrication on commercial P4 machine
- Resin infusion of part
- Demonstration of large P4 manufacturing cell

National Educators' Workshop

Mini Workshop:

Vacuum Assisted Resin Transfer Molding (VARTM) for Fabrication of Bridge Decks and Other Structural Applications

VARTM Mini Workshop

- **This workshop will demonstrate the Vacuum Assisted Resin Transfer Molding process used to make structural composite parts.**
- **The workshop will include:**
  - **A "words and pictures" overview of the VARTM process**
  - **Examples of parts made with VARTM**
  - **Hands-on demonstration giving participants an opportunity to make a small composite "bridge deck"**
  - **Live-load "testing" of the parts made by workshop participants!**

What is VARTM?

"An infusion process for making Fiber Reinforced Polymer (FRP) parts, in which a vacuum draws resin into a one-sided mold. A cover, either rigid or flexible, is placed over the top to form a vacuum-tight seal."

VARTM Process - Overview

- Design the Part – Dimensions, Fiber Architecture, Resin Characteristics, etc.
- Build the Mold Tool
- Assemble the Part:
  - Place Dry Fiberglass Cloth, Closed-Cell Foam "Block-outs", and Embedded Parts in Mold
  - Place Vacuum Tubes and Resin Transfer System in Mold
- "Bag" the Part With Airtight Plastic Film Held in Place By Double-Sided Tape

VARTM Process – Overview cont'd

- Apply Vacuum to Evacuate Voids and Consolidate the Fiberglass
- Inject Resin, Filling All Voids and Saturating the Fiberglass
- Let the Part Cure in the Mold
- Remove Vacuum Bag, Tubes, and Resin Transfer System
- Remove the Finished Part From the Mold

Advantages of VARTM

- Allows the Fabrication of Complex Three-Dimensional Fiber Architecture
- Room Temperature Processing and Curing
- High Fiber-to-Resin Ratio
- Low Void Content
- Relatively Low Vacuum Required (>14 psi)

Advantages of VARTM cont'd

- Very Low VOC Emissions
- Adaptable to Wide Variety of Part Sizes and Geometries
- Minimal Tooling Requirements
- High Finish Quality and Good Dimensional Control

VARTM Demonstration

- Overview of The VARTM Process
  - Materials and Equipment
  - Set-Up and Assembly
  - Making the Part and Curing
- Become Familiar with "Raw Materials":
  - Fiberglass, Resins, and Foam
  - Mold Tool
  - Vacuum Bagging Components
  - Resin Distribution System Components

VARTM Demonstration cont'd

- Hands-On:
  - Place Fiberglass, Foam Blocks, Vacuum Tubes, and Resin Distribution System in the Mold
  - Assemble the Vacuum Bag
  - Apply Vacuum and Assure Airtight Integrity
  - Inject Resin
  - ***Resin must cure for several hours, so….***

VARTM Demonstration cont'd

...the next day...

- During a Break, You Can Observe the "Un-bagging" Process and See the Finished Part
- The Strength of the Finished Part Will Be Demonstrated Under "Live Load" Conditions

VARTM Mini Workshop

- Take-aways will include:
  - Instructions for VARTM Laboratory Session
  - Materials and Parts List for Lab Session
  - List of Suppliers
  - "Interest Stimulators" – ideas for class/lab discussion:
    - What potential problems should be anticipated and avoided during fabrication?
    - How do you know the part was made properly?
    - What is the "calculated strength" of the part?
    - What are the predicted failure modes?
    - How can the finished part be tested?

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2001	Conference Publication

4. TITLE AND SUBTITLE
National Educators' Workshop:Update 2000
Standard Experiments in Engineering, Materials Science, and Technology

5. FUNDING NUMBERS
WU 706-17-41-22

6. AUTHOR(S)
Compiled by Edwin J. Prior, James E. Gardner, James A. Jacobs, and Louis A. Luedtke

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER
L-18105

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration, Washington, DC 20546-0001; Norfolk State University, Norfolk, VA 23504; National Composite Center, Kettering, OH 45420; National Institute of Standards and Technology, Gaithersburg, MD 20899; Department of Energy, Oak Ridge, TN 37831; Wright-Patterson Air Force Base, OH 45433; University of Dayton, Dayton, OH 45469; Gateway Coalition, Drexel University, Philadelphia, PA 19104

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/CP-2001-211029

11. SUPPLEMENTARY NOTES
Prior and Gardner: Langley Research Center, Hampton, VA; Jacobs: Norfolk State University, Norfolk, VA; Luedtke: National Composite Center, Kettering, OH

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified–Unlimited
Subject Category 23 Distribution: Standard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT ***(Maximum 200 words)***

This document contains a collection of experiments presented and demonstrated at the National Educators' Workshop:Update 2000 held in Dayton and Kettering, Ohio, October 29–November 1, 2000.

14. SUBJECT TERMS
Materials; Experiments; Education

15. NUMBER OF PAGES
627

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL